CAN PERCEPTION FOOL COGNITION?

INTERACTION OF VESTIBULAR AND COGNITIVE PROCESSES IN TIME PRODUCTION, SPACE PERCEPTION AND MENTAL ROTATION

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CONTENT

SUMMARY

"[]…cognitive phenomena of perception can violate laws of physics. So, it seems that physics is not a reliable guide for cognitive theories."

GREGORY, R.L. (2004)

The following work aims at investigating situations where cognitive demands are accompanied by consonant, dissonant or irrelevant sensory stimulation (vestibular, visual). Various studies have elucidated the reciprocal relationship of bottom-up processes (here referred to as "sensory" or "perceptual" influence) and top-down processes (here referred to as "cognitive" influence). Selected examples of vestibular influence – given by stimulation of the semicircular canals, otolith stimulation or the direction of gravity relative to participants or inherent to the stimuli used aim at defining the scope of influence on cognitive processing such as time production and mental rotation.

This thesis is divided into two sections:

Part I deals with selected examples where cognitive (top-down processes) and perceptual (bottom-up, sensory signals) information are concurrently presented and investigates in what way this alters performance in a given task.

The first three experiments deal with **"Influence of Perception on Cognition"**. The experiments are situated in the field of basic research on time production during vestibular stimulation. These studies were inspired by previous research that suggests an influence of vestibular stimulation on distance and time perception (ISRAËL ET AL, 2004) and aims at testing and reassessing the effect of high velocities during prolonged stimulation of the semicircular canals (EXP ACC-DEC), during minor constant roll movement or in static roll positions activating only otoliths (EXP ROLL & POS). In the first experiment (EXP ACC-DEC) with very high acceleration and deceleration about the z-axis (yaw-rotation), the slope of time productions (i.e. constancy of interval productions in the course of time) showed a significant effect (slopes changed distinctively for acceleration and deceleration) for short intervals (1s). In EXP ROLL very low constant passive rotation velocities applied in the ROLL axis (otolith stimulation) showed no effect on time productions. However, when positioning participants in static roll positions (EXP POS) time productions showed a significant increase for the positions 90° and 135° compared to the baseline in an upright position (0°) again only for the production of short intervals (1s). This result suggests that cognitive processes were triggered when remaining in unusual and confusing positions which lead to attention being shared between perceived body position and time production and a concurrent increase of cognitive load for short intervals. The continuous movement in EXP ROLL on the other hand was shut out easily and did not affect the time production task. Altogether, participants seemed quite resistant to vestibular distraction if was not of a magnitude that at the same time lead to high arousal or required attentional resources being shared.

The next experiment on **"Influence of Cognition on Perception"** investigates the influence of visual information (visual motion illusion) on apparent body tilt. People are quite precise when asked to adjust themselves to a fully horizontal position in complete darkness (JARCHOW, 2002).

The experiment (EXP ILLMOVE) conducted here showed that a visual illusory motion (with no implicit direction) was able to change the consistency of adjustments by adding noise to the system, resulting in a higher variability (standard deviation) of adjustments. The average adjustments of body tilt were not affected, yet participants conducting the illusion condition as the second condition also showed a trend of altered average adjustments between the two conditions.

Part II "Cognitive and Perceptual Factors in Mental Rotation" presents several experiments on mental rotation. The studies focus on different factors: EXP POS-PICT and POS-DEPTH investigate mental rotation of body figures during altered body position of participants (upright, supine, side and prone) to elucidate if the direction of gravity enables other processes and strategies in a left-right decision task. The results showed a quite asymmetric course of reaction times with increasing angular disparity from the upright for the depth-plane condition (figures rotated about a y-axis), yet the effect of condition did not reach significance. The side position evoked a slight displacement of maximal reaction times suggesting a shift of reference frame applied for the task. EXP PLANE compares different rotation axes (picture and depth plane) of the presented human figure, testing the effect of rotation axes more specifically. A clear asymmetry was again found for the depth plane condition where reaction times peaked at 225° instead of 180° as seen in the picture plane condition. A more allocentric mental rotation task is provided in EXP HANDSHAKE, where in a false-correct task modified versions of the human figure require imagining shaking the figure’s hand, therefore rendering the front position more easy. This task was conducted for body figures rotated in the picture plane and depth plane. The clear reversal of the view-effect (front or back) was not fully affirmed, yet the data indicated a trend in that direction. For some participants reaction times in the depth plane rotation no longer showed the interaction effect between the factors view (front, back) and angle of rotation. This favors the assumption that spatial compatibility could be relevant for the interpretation of the data. A direct comparison of object-based versus egocentric perspective transformation is given in EXP OBJEGO. This experiment aimed at triggering different spatial transformation processes by assessing mental rotation with cameras where participants were explicitly asked to imagine rotating the camera to the upright position, as well as with body figures where participants were asked to take over the perspective of the figure (first-person instruction). Surprisingly, the results showed no significant difference between the two conditions. Finally, in EXP 3D, investigation of a variety of different rotation axis and views revealed that it took more time to rotate face-up figures than figures that are face down. This further stresses the interrelation of familiarity and mental rotation.

There is a wealth of knowledge in the research area of mental transformation. Many aspects of the processes studied so far could be affirmed by the present studies, other results add to the body of knowledge. The results of the studies suggest that body figures trigger egocentric transformation. In contrary to previous findings (e.g. ZACKS, 2000) but in line with others (e.g. PARSONS, 1987A) this did elicit strong orientation effects, especially for figures presented from the back and figures rotated in the depth plane which calls into question the use of the term egocentric transformation as applied in previous research.

All of the experiments apply psychophysical methods to assess the performance of participants. Research area is restricted to human time and space perception.

INTRODUCTION AND OUTLINE

"What we say about reality depends on the perspective into which we throw it. The *that* of it is its own; but the *what* depends on the *which*; and the which depends on us."

W. JAMES (1907)

The initial idea for the experiments investigating vestibular influence on time perception, as well as the inspiration to test the effect of human body position on mental transformation processes was given by Prof. Fred Mast. The other experiments evolved from problems or questions raised by the preceding experiments. Furthermore, Prof. Isabel Israël and her doctoral student Aurore Capelli initiated and were involved in the beginnings of the vestibular experiments conducted at the Department of Neurology at the University Hospital of Zurich. All of the other experiments were conducted in the laboratory of the Department of General Psychology (Cognition).

The definition of cognition is not clearly distinguishable from perception. The concept of cognition is closely related to abstract concepts such as mind, reasoning, perception, intelligence, learning, and many others that describe numerous capabilities of the human mind and expected properties of artificial or synthetic intelligence. Most commonly, cognition is defined as the psychological result of perception, learning and reasoning. According to STEWART (1996), there is a definite tendency to consider the computational theory appropriate for "high-level" human cognition, whereas the constructivist approach is appropriate for "low-level" cognition. The differentiation between perception and cognition as discussed here is not common in literature, where perception as mentioned before is part of what results in "the composite cognitive activity". The following exemplifications illuminate how the terms used in the present work are understood:

The word *cognition* derives from the latin word cognoscere which means as much as "to get to know" (from com=together + noscere=to know). It refers to higher level processes where mental activities are involved in the acquisition and processing of information (thinking process, memory, experience, strategies). Compared to sensory reactions, cognitive processes can be slow adaptations to a given situation. They are conscious and relatively voluntary. Cognitions however can be consonant as well as dissonant (FESTINGER, 1957). It is possible to manipulate them and they are possibly flawed or erroneous (ZHAOPING, 2007) as is seen in various examples where cognitive interpretations are subject to illusions. Emotion and arousal can influence how we cognitively process information and can evoke strategies. Mental imagery is a striking example of how humans are able to cognitively generate an image of what an object looks from the other side, how a song will sound by looking at a sheet of music or how a gymnast will have to be instructed to fulfill a given exercise.

The word *perception* refers to lower-level processes. It describes the process of becoming aware of something via the senses, the knowledge gained by perceiving. Sensory information – the basis of perception – is generated fast and often involuntarily (e.g. reflexes). It is automatic and more "correct" compared to cognitive information (ZHAOPING, 2007). Perception can be unconscious and on a phenomenal level. Interaction of the senses is important; during the generation of a percept, information of the different senses influence each other (support, contradict) which may also add noise to the system.

The term most suitable for what is investigated in the following experiments is *cognitive perception.* This expression has been used to describe the interpretation and processing of a percept. Here I specifically include perception influenced by knowledge that is not directly part of the perceptual source. The focus is set on the question as to how cognition is able to influence what we perceive (top-down triggering of low level perceptual processes). Generally, cognition – the interpretation vs. mere processing of a perceptual stimulus – is hard to shut out during "perceiving", people are bound to analyze and consider any information present. On the other hand, *perceptual cognition* describes a bottom-up mechanism where information flows from perception to cognitive processing; the modular sensory processes are cognitively impenetrable (PYLYSHYN, 1991), that means that their representations and much of their operation is unaffected by our beliefs, plans, and conscious processes. In this work the term is used for perceptual influence on cognition not directly relevant to the cognitive processes. The question posed is how sensory information influences how we cognitively interpret and process information ("apperception"; bottom-up triggering of cognitive processes). The activation of motor processes during mental rotation tasks is later discussed in this context.

I chose this topic because multisensory aspects of our actions are of major significance in everyday life. The focus of interest lies on the topic of how strongly compensation for interfering information is reached and managed. The following questions are of crucial interest: What are the factors constraining an efficient use of the information provided by the sensory information? How does additional consonant or dissonant sensory information influence and distract other sensory information? Can task-irrelevant sensory information be successfully shut out? How stable are mental processes in the course of time? How does experience improve performance? These questions aim at giving an insight as to what extent sensory and perceptual information (bottom-up) can alter cognitive processes, and vice versa, how cognitive knowledge can influence what we perceive (top-down). The aim of this work is to enlighten the relationship between cognition and perception by giving examples of situations where sensory information and cognitive processes come into play. The major question is to what extent concurrent cognitive information (cognitive, such as knowledge of our own position or knowledge acquired such as time intervals and what hand we use to make a correct handshake) during a perceptual psychophysical task can alter (improve or impair) performance. This concurrent information may be consonant (same direction, improved performance?), dissonant (distraction, impaired performance?) or task-irrelevant. The latter experimental situation may still lead to an increased cognitive load and therefore also cause impaired performance. The same effect is focused for the opposite situation where sensory stimulation is applied concurrent to a cognitive task (such as vestibular stimulation during time productions, body position). Can we effectively benefit from additional information provided? Can we also effectively shut out irrelevant information?

Body image is a concept relevant in all of the experiments conducted: how does the perception of our position in space, or the interpretation thereof affect cognitive processes? Is the allocentric frame of reference crucial for mental rotation? Do we rely on object-centered or merely egocentric cues to make a decision?

Experiments Conducted

As mentioned, the situations focus on whether concurrent information of the two "systems" – cognition and perception – contradict or override, dominate or disturb each other (e.g. as in Experiments ACC-DEC, ROLL, POS, ILLMOVE). This could the case when one system provides only ambiguous information and allows one system to dominate the other and which facilitates false interpretations. Also, unfamiliar or unnatural perceptual stimulation can lead to cognitive processes (apparent logical interpretation) having little to do with the actual physical condition (e.g. in Experiments ACC-DEC, ROLL, POS); can perceptual irrelevant information be successfully ignored? Is the kind of vestibular stimulation applied here able to manipulate time productions or is it too automatic to bias time production? How are cognition and self-perception (body image) linked? (e.g. mental rotation experiments in Chapter II).

The present work contains three experiments on "perceptual cognition" where participants are asked to produce time intervals continuously during different vestibular stimulations:

- EXP ACC-DEC: Strong constant acceleration/deceleration in the YAW-axis (semicircular canals),
- EXP ROLL: Constant roll movement at 1.96°/s (otolith stimulation), and
- EXP POS: Static positions in the roll plane (otolith stimulation)

A further experiment deals with "cognitive perception" where a motion illusion is presented during adjustment of perceived horizontal body position.

- EXP ILLMOVE

Finally, six experiments deal with mental transformation of human figures. The interest of this part of research is on the one hand the influence of perception (sensory inputs on our position in space) on cognition (mental rotation of body figures). In two of the experiments body position of the participants is systematically varied to investigate if the perception of position influences performance in a mental rotation task depicting a human figure which evokes a first-person transformation:

- EXP POS-PICT (1a and 1b): Human figures rotated in the picture plane , and
- EXP POS-DEPTH: Human figures rotated in the depth plane

On the other hand, general transformation processes and strategies are focused by varying aspects:

- EXP PLANE: the rotation axis of the presented figures,
- EXP HANDSHAKE: the presented figure and frame of reference,
- EXP OBJEGO: comparing objects with human figures, and
- EXP 3D: further expansion of the range of angles of rotations in 3-dimensional space

A wealth of knowledge exists in the area of mental transformation. Mental rotation describes the cognitive ability to imagine an object and to rotate it in mind. By measuring how much time such operations take, we can tell something about how people represent images in their minds. Different paradigms vary in various aspects such as the kind of stimuli used (human figures: e.g.

PARSONS, 1987A / objects: e.g., SHEPARD & METZLER, 1971), the task parameters (left-right, same-different, e.g. PARSONS, 1987A & B; ZACKS ET AL., 1999; ZACKS ET AL., 2000; ZACKS ET AL., 2002; ZACKS, VETTEL & MICHELON, 2003), the kind of transformation (egocentric / object-based and first- and third-person instruction) or the manipulation of instructions (e.g. ZACKS & TVERSKY, 2005). The paradigm of SHEPARD and METZLER (1971) applied in mental rotation of objects has influenced experimental psychology for more than a quarter of a century. Literature on body image postulates a real-time representation of ones body in space, generated by proprioceptive, somatosensory, vestibular and other sensory inputs. These representations are referred to as body schema (SCHWOEBEL ET AL., 2001). They are the basis for experiencing posture and movement, for the sense of space and for the ability to perceive objects and creatures. The process of imagined spatial transformation is compared to an out-of-body experience where the innate visual perspective and perception of oneself are externalized (BLANKE ET AL., 2005).

The limits of previous mental imaging studies are situated in the kinds of stimuli used and range of rotation axes (with the exception of PARSONS, 1987A). Furthermore, there seem to be contradicting results on whether rotations of objects and human figures are dissociable or based on the same processes. The following experiments investigate how clear this differentiation between egocentric and object-based transformations can be made and allow assumptions on what factors can improve, favor or alter one or the other process.

The measurements taken are response times (RT), error rates (ER), standard deviation (SD) and introspective reports.

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I. INTERACTION OF PERCEPTION AND COGNITION

1. Influence of Perception on Cognition (Bottom-Up)

1.1. Introduction

"We have no sense for empty time."
W. JAMES (1890)

Perception – Cognition

The influence of vestibular signals on time perception has received some attention in the last few years. Yet, the fact that time perception is quite a broad area of research, these studies differ in many ways which renders comparisons and conclusions difficult. We here aim to expand results found by ISRAËL ET AL. (2004): when participants are asked to reproduce a given distance, they seem to keep track of time by counting aloud or report doing so quietly. The interrelation of time and space can not be called into question; one is inherent in the other. The question of interest is to what extent time perception influences how we perceive distance and – as is focused on in the following study – how concurrent vestibular signals are able to alter time production. The studies conducted furthermore pose the question of how signals of the semicircular canals and otolith signals distinctively influence time production. Time perception and vestibular processing both have in common that they are only then consciously processed and perceived when we direct attention to them. Given the task of time production, attention is here directed to time, while the vestibular signals are kept task-irrelevant and can be ignored as far as that is possible. A short introduction to the basics of time perception, as well as factors involved in and interacting with time production are given in the following.

Time Perception

The concept of time perception has been studied by many different disciplines. Time has always been of interest in philosophical thinking and is a crucial concept in physics. A major significance however lays within the fact that time shapes our behavior and our thinking in almost all areas of our daily lives. Biological rhythms are relevant for practical human situations, social life submits to temporal rules, rituals follow rules of duration, simultaneity and succession; speech, music, and motor skills show fine temporal tuning patterns and finally our memory is organized along temporal structures. Besides automated temporal processing we have conscious time experiences such as anticipation of future events, feeling of time pressure, and retrospective consideration of elapsed time (HELFRICH, 1996).

PAUL FRAISSE'S book "Psychologie du temps" in 1957 was a milestone for the psychology of time and gave rise to a large amount of follow up studies in the area of psychology. FRAISSE (1963) was the first to emphasize that a discontinuity in our sense of time is evident around 2-3 seconds. LEWIS AND MIALL (2003) suggest that timing in the shorter range is "automatic", reflecting the engagement of processes associated with the production of skilled movements. Longer range timing is hypothesized to be "cognitive", dependent on neural systems associated with attention and working memory (IVRY & SPENCER, 2004A). Studies on time perception vary with their focus set on perception, estimation or recall of time intervals and in the last years the interest has expanded to more multiperspective view stretching from basic psychobiological processes to cross-cultural aspects. This has also lead to a gap between biological and cognitive approaches to temporality (HELFRICH, 1996).

Models of Psychological Time

Theorists have taken two seemingly different approaches to explaining, or modeling psychological time (BLOCK, 1990). ORNSTEIN (1969) referred to them as the sensory-process approach and the cognitive approach. *Sensory-process models* postulate some sort of "time-base", a repetitive, cumulative, pulse-dispensing mechanism which delivers internal time signals, an "organ" of time (BLOCK & ZAKAY, 1996). ORNSTEIN claimed that this type of model has failed to provide a useful way to understand the experience of duration. This approach also has difficulties explaining why cognitive – or information-processing – variables influence the experience of duration.

Methodologically and conceptually the psychophysics of time has been consistent with the behaviorist tradition in experimental psychology. Models have usually been of the "clock-and-regulator" type. This implies that, whatever variable is studied for its effect on subjective timing rate, it is considered to affect the rate of an internal clock which, as a result, will slow down or speed up, thus creating the subjective feeling of time dragging or accelerating (TREISMAN, 1963). TREISMAN refers to this pacemaker mechanism underlying the psychological timing system (chronobiological models). He proposed an influential model of an internal clock as the basis of human temporal judgment and postulated a pacemaker that produces a regular series of pulses, the rate of which varies as a function of input from an organism's specific arousal center. This specific arousal is influenced by external events, in contrast to general arousal, which depends on internal mechanisms such as those underlying circadian rhythms. A hypothesized counter records the number of pulses in a pathway and the total is transferred into a store and into a comparator mechanism. A verbal selective mechanism assists in retrieving useful information from the store. There is presumably a long-term memory store containing knowledge of correspondences between total pulses and verbal labels, such as 3s, 1m, and so on. A later modification of TREISMAN'S model includes a calibration unit that modulates the pulse rate. Irrespective of the details of the numerous models in this tradition, they all strongly rely on a clock metaphor and as such they may in fact be reduced to simple variations on the theme of time measurement or chronometry.

The other class of models, the *cognitive approach*, includes various proposals concerning the important cognitive factor underlying duration experience, such as "images" (GUAY, 1890, 1988), "changes" (FRAISSE, 1957; 1963), "mental content" (FRANKENHÄUSER, 1959), "storage size" (ORNSTEIN 1969), and "contextual changes" (BLOCK & REED, 1978) but does not include a timer as the formerly mentioned approach. Cognitive models cannot easily explain the near-linear psychophysical relationship between physical and psychological duration, as well as the possible influence of physiological variables such as body temperature (e.g. HANCOCK, 2004).

In time theories without a timer, psychological time is constructed from processed and stored information (attentional models, memory storage models and memory change models, BLOCK, 1990). The *Attentional Gate Model* described by BLOCK AND ZAKAY (1996) contains two important modifications to expand internal-clock models. First, it incorporates the notion that a subject may divide attentional resources between attending to external events and attending to time (THOMAS &

CANTOR, 1975; THOMAS & WEAVER, 1975), and it specifies the consequences of each. Less attention to time leads to diminished processing of time information and to an increase of the subjectively perceived time. Attending to time is necessary for pulses to be transmitted to a cognitive counter. While the duration is in progress the number of transmitted pulses is a function of two factors: the pulse rate (influenced by general and specific arousal) and the proportion of time the gate is open or the width it is wider. The gate is opened on each occasion on which an organism attends to time and the width is influenced by amount of attention allocated to time. In the revised *Attentional Model* (e.g. ZAKAY & BLOCK, 2004) changes of prospective time estimations are ascribed to cognitive load. When other activities are being conducted during prospective time estimation and therefore attention is being shared, this leads to a decrease of experienced duration (intervals produced too long) and to a higher variation of interval production (as shown by BROWN, 1997).

The important difference between the two theories is not that the first concerns sensory processes and that the second concerns cognitive processes. Instead, the first class of model proposes timing with a "timer", whereas the second proposes timing without a "timer" (IVRY & HAZELTINE, 1992).

Objective Time

Time representation can be concrete or abstract. It may be divided or "measured" in terms of observable events such as moon cycles. The opposite of this concrete representation of time is the abstract representation according to which time units – such as seconds, minutes, hours or weeks – are independent of environmental events and are compatible with one another (e.g. FRIEDMAN, 1990). The method of time production is a strongly cognitive process, in the presents work this is obvious due to the assignment to produce this abstract and learned concept of time (1, 3, 8 or 15 "seconds").

The expressions "under-" and "over-estimation" are often encountered in literature on time perception (e.g. PETROVICI & SCHEIDER, 1994; ST. JEAN ET AL., 2004), however these terms are ambiguous (HICKS ET AL., 1976) and lead to confusing interpretations. The ambiguity is clearest in reproduction experiments; does "over-estimation" refer to the standard, thereby implying that reproduction is comparatively too long, or to the reproduction, implying that it is comparatively too short? The same problem appears in other psychophysical methods. In time estimation for instance, an estimate exceeding the standard (e.g. 3 seconds are estimated as 5 seconds) may be due either to the time interval being experienced as longer, or to the unit of measurement (subjective seconds) being too short. The problem becomes clear when duration is experienced as being longer than a standard. One would say that it is overestimated when using an estimation method (3 seconds are produced when 5 seconds are requested) a rather unsatisfactory description of what is going on (HELFRICH, 1996). In the following experiments – if necessary – over-estimation refers to interval productions that exceed the standard.

Factors Influencing Time Perception

Everyday experience shows, that in the absence of external time markers, such as clocks, the estimation of short time intervals strongly depends on the focus of attention; time flies when we are having fun and a task absorbs our full attention, but seems to stand still (a watched pot never boils) when a task is boring (e.g. FUNKE & GRUBE-UNGLAUB, 1991; PÖPPEL, 1997). In retrospect, the reverse takes place; the accelerated time is subjectively extended and in the latter example time is subjectively shrunk similar to the optic OPEL-KUNDT illusion (KUNDT, 1863; OPEL, 1855, see Figure 1) where the "empty space" between two lines appears narrower than the space filled with other lines, even though the distance is exactly the same. An explanation of this paradox concerning time is that a time period filled with a demanding task imprints more and richer traces in memory, whereas periods where nothing or little happened, will leave only a few traces (e.g. BLOCK & ZAKAY, 1996; FRIEDMAN, 1990). The perception and processing of the flow of time are not constant but depend on "the state of mind of the observer" (EINSTEIN, 1938). This so-called interference effect (i.e. the effect of non-temporal tasks on perceived time) is consistently found in the literature of time perception (for review see BROWN 1997). There is ample evidence that attention-demanding stimuli (e.g. interesting or difficult tasks) affect perceived duration, but not remembered duration. The role of attention in perceived duration judgments is interesting, because it provides a point of contact between the cognitive and the neuro-scientific research.

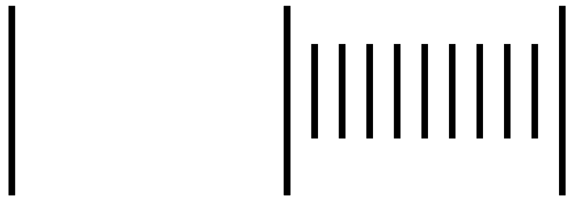

Figure 1 The OPEL-KUNDT illusion (KUNDT, 1863; OPEL, 1855) is one of many contextually dependent size illusions; the empty part on the left seems narrower than the filled part on the right.

Biological time of human organisms may be studied on a macro level (biological events such as birth, sexual maturation or death) or on a micro level referring to recurrent cycles such as activity rest, sleep-wake, heartbeat or temperature cycles (chronobiological models). Chronobiologists typically study cyclical phenomena by seeking the physiological basis of oscillators or pacemakers (BLOCK, 1990). There are a number of biological processes which form periodically repetitive events. Such rhythms are heartbeat, breathing or the sleep-wake cycle (HELFRICH, 1996). Some "biological" (physiological) factors have been shown to influence time perception: Several studies have shown that *arousal* and *activation* (as operationally defined by the authors, such as acoustic noise, see OZEL, LARUE & DOSSEVILLE, 2004) can affect time estimation suggestively by leading to an acceleration of the internal clock. It was found that magnitudes of produced durations are highly correlated with subjective workload ratings and with performance indices, without interfering with performance (ZAKAY & SCHUB, 1998). Activation levels have been manipulated in a number of ways, such as manipulation of circadian rhythms and administration of drugs (GUPTA & CUMMINGS, 1986) and increase or decrease of *body temperature* (FOX, BRADBURY & HAMPTON, 1967; HANCOCK, 1993[1]; HANCOCK, 2004). WEARDEN AND PENTON-VOAK (1995) suggested that increased body temperature influences general arousal level, which thereby influences the rate of a pacemaker mechanism. These authors found that increased body temperature leads to subjective time run faster. Incrementing physical activation level has been found to retrospectively cause an over-estimation of perceived time. The problem with postulating that a pacemaker or master biomechanical clock directly influences time related behaviors and judgments is that temperature may also influence brain processes that subserve attentional, memory, and other cognitive processes. Variations in these processes probably have little or no effect on body temperature. Because cognitive variables (such as attentional demands of a task) influence duration experience, cognitive processes may directly mediate temporal behaviors and judgments. Body temperature may indirectly influence

[1] The term "chemical clock" has been used to imply a causal link between body temperature and perception of time duration.

temporal behaviors and judgments by altering whatever cognitive processes subserve psychological time (BLOCK, 1990).

Other, more "cognitive" factors are also known to influence time perception. ANGRILLI ET AL. (1997) highlight attention and the extent of information processing. Attentional models of time perception have proposed that, during a time judgment task, attentional resources allocated to the stimulus are subtracted from the attention that individuals devote to the processing of time. As a consequence, when an interesting stimulus or a stimulus that requires more attentional resources is presented during the interval to be estimated, fewer time units are processed (see, e.g. THOMAS & WEAVER, 1975; TREISMAN, 1963; ZAKAY, 1993). Temporal and non-temporal information share these common attention resources (ZAKAY & BLOCK, 2004). Like a computer, the mind has a limited capacity (shared resources), and tasks will slow down if there are too many running at once (cognitive load is increased). Interference describes the mental slow-down and other problems that result from the mind trying to do too much at once (as in a dual-task situation). Interference however only occurs when two processes draw on the same limited resource. Some psychologists criticized research on attention and time perception, because many of the experiments designed to show the effects of splitting attentional resources use stimuli that at the same time also increase the level of arousal. This confound is difficult to remove, because the tests for increased mental load (the allocation of more attentional resources) also tend to affect the level of arousal. To test whether the level of arousal affects perceived duration judgments, ANGRILLI ET AL. (1997) manipulated participants' arousal levels during stimuli presentation, and asked for duration judgments. In addition to the arousal level, the emotional valence of the stimuli was also varied. Some stimuli carried a positive valence (with either high arousal, e.g., slides depicting sexual content, or low arousal, e.g., slides with photos of babies or puppies), while others carried a negative valence (with high arousal, e.g., human wounds, or low arousal, e.g., spiders and rats). They found that arousal did affect perceived duration judgments, and that effects differ depending on the emotional valence of the stimuli. When participants' arousal level was low, they tended to judge negative slides as having shorter durations, and positive slides as having longer durations. This effect was reversed for high levels of arousal, with the durations of positive slides being underestimated relative to estimations of neutral slides, and the durations of negative slides being overestimated. ANGRILLI ET AL. (1997) hypothesize that at low arousal, the allocation of attentional resources can affect time-perception, with negative slides receiving more attention, and therefore shorter duration estimations. However, attentional factors do not seem to be at play during high arousal judgments. The authors therefore assume that the level of arousal controls two different motivational mechanisms for time perception: an emotionally driven one and a non-emotionally driven system. The former acts with high arousal and produces an over-estimation of produced time interval with negative valence. The emotional system is only active for a short period of time (<2s).

"Short" and "Long" Time Intervals

The length of presented intervals is quite important in reproduction tasks. ALLAN (1979) stated that humans are very accurate measurers of time at comparatively short intervals, with both the mean perceived time and the standard deviation; the function of this relationship has a slope near 1. The linear relationship between duration and the standard deviation of duration judgments indicates that time perception obeys Weber's Law, such that the absolute sensitivity of time judgments is independent of the length of the actual duration. Intervals up to a few seconds can be reproduced comparatively exact, while longer intervals are generally reproduced too long. This is explained with a *temporal integration mechanism* (TIM), a hypothetical model suggested by PÖPPEL (1997). The TIM binds the sequences of elementary events together into perceptual or conceptual units of approximately 3s durations. This represents the impression of the "subjective present" or our feeling of "nowness". Proof for the existence of a 3s-window is found in the exact time perception in speech, motor skills, memory, as well as in the visual and auditory domain (SZELAG ET AL., 2004). Furthermore, temporal information processing can be separated into two units: the "low-frequency processing level" and the "high-frequency processing level". The latter is limited to time windows of about 30-40ms. Events within the processing unit (system state, see PÖPPEL, 1997) are treated as simultaneous and integrated into a unit. The relationship of the two events (first and last) can no longer be acquired. The temporal order threshold lies within 20-60ms and seems to be similar in different sensory systems (visual, auditory, tactile).

WEARDEN ET AL. (1998) hypothesize that auditory stimuli run the pacemaker with a faster rate than visual stimuli (see Scalar timing model[2] in ALLAN 1998). For the auditory and visual system an inter-stimulus interval of 40ms is necessary to correctly identify 75% of temporal order. Interestingly, for a very short inter-stimulus-interval of only 5ms there are significantly more correct answers in the auditory domain (68%) compared to vision (46%). This bias lasts up to 40ms. The difference is explained with different transduction mechanisms on the level of receptive cells - the auditory system features a higher temporal resolution (SZELAG ET AL., 2004). When comparing the visual and auditory modality, sound is perceived longer than light.

In respect to methodological and stimulus-related factors FRAISSE (1984; also see BLOCK, 1989; HICKS ET AL., 1976) gives an overview of factors shown to influence short intervals (also see WEARDEN ET AL., 1998). a) The nature of the *measurement paradigm* (e.g. prospective paradigm vs. retrospective paradigm) and the *method* of time estimation (type of time judgment); ZAKAY AND BLOCK (2004) find that reproductions are too short in prospective tasks and produced too long in retrospective tasks. In their view the former finding supports an attentional model involved in prospective timing while the latter is explained with the activation of executive functions producing contextual changes encoded in memory. Yet other origins of influence are: b) the *duration* and *intensity* of the interval. The more intense the stimuli, the subjectively longer they are perceived compared to less intense stimuli and c) the nature of *processing required* of the subject during the interval to be estimated. It has been shown that short intervals are reproduced shorter when they are empty than filled (external or internal events that occur during that period, nr of events, content, complexity, modality) as is the case with the Opel-Kundt illusion.

Development of the Time Concept

The exactness of time (re-)productions changes in the course of different development stages. SZELAG ET AL. (2004) studied different age groups (6-7, 8-10 and 13-14 years of age). The participants were to reproduce visual (a green rectangle presented on the screen) or auditory (200 Hz tone) standard durations, ranging from 1 to 5.5s. The authors found that in the three age groups

[2] The scalar timing model has generally involved intervals of up to 40s. Timing within this range is assumed to involve a set of separable components including a pacemaker, accumulator, gating mechanism and decision processes in which the output of the accumulator is compared to reference memory of stored intervals.

studied, standards of approximately 2.5s were quite accurately reproduced, whereas those longer than 3s were reproduced too short. Substantial age-related differences in accuracy of reproduction were observed for standards shorter than 2s. Pre-scholars usually over-reproduced these standards substantially. Both groups of school children showed comparatively accurate reproduction (for detailed statistics see SZELAG ET AL. 2002), but the youngest group tended to under-reproduce longer standards compared to the older participants. The authors explain that development-related changes of cognitive skills and temporal information processing are allocated to the prefrontal- and parietal cortices. Furthermore it has to be considered that distraction of motor reaction (button press) might cause an over-produced interval and impatience on the other hand can lead to reproductions being too short.

In all time production experiments it is important to consider that tasks are always confounded with motor timing functions (e.g. button press). An interesting observation was made by SEMJEN (1996) who showed that the shorter the interval, the shorter the contact time with the button. This could be relevant when intervals are compared (SEMJEN tested 300ms, 600ms and 900ms intervals). An interesting result on different cognitive strategies in time estimation is found by GUAY AND WILBERG (1983) who report that "time aiding cues" such as counting aloud or auditory signals do not lead to better performance (1s, 2s, 4s).

Space and Time

Various sensory inputs, in particular visual, proprioceptive, and vestibular inputs, are used to determine the orientation of the body with respect to gravity (PAVLOU ET AL., 2003). Vestibular cues are usually equated with the tonic afferent input from the otolith organs and central graviceptive pathways (BRANDT & DIETERICH, 1994; MILLER & GRAYBIEL, 1966). Two systems of the vestibular system are distinguished. The *semicircular canals* are responsible for non-linear acceleration. According to BENSON ET AL. (1986) "human exposure to a rotational acceleration of around 2°/s or lower is below the detection threshold of the semicircular canals". BENSON (1989) summarized the findings of several researchers on the functional thresholds of the vestibular system. He reports that, using a seat free to move in the x- or y- body axis, the threshold for detection of tilt from the vertical is on the order of 2°. The *otoliths* detect translation and linear (gravito-inertial) acceleration of the head – they are not able to distinguish if the head is tilted or if it is movement linearly in respect to the ground. The ability to distinguish and correctly interpret these movements stems from concurrent activation of the semicircular canals. During ROLL-movement this leads to a different interpretation of the otolith-signal (MERFELD, ZUPAN & PETERKA, 1999). Otoliths are able to measure linear movement (gravity) for velocities lower than 2°/s. KHILOV (1974) suggests that otoliths have an inhibitory effect on the semicircular canals. When otolith signals are absent as in outer space (zero G) the threshold of semicircular canals is dropped. KHILOV (1974) explains vegetative reactions with this hypersensitivity of the semicircular signals.

MITTELSTAEDT AND MITTELSTAEDT (2001) compare active or passive estimations of path lengths during passive translation. They found subjects undershot a given target at low velocities and overshot it at high velocities. They behaved as if they overestimated the path length at slower motion and underestimated it at faster motion. This effect is reversed in active movement. In a more recent study, GLASAUER (2007) confirmed the finding that participants overshot distances at higher velocities and undershot them at slow velocities.

LEBENSFIELD AND WAPNER (1968) show the dependence between time and space for short intervals (range .1s to .7s) using a paradigm with light and touch being presented successively in three positions in space; either of the two independent variables (e.g. temporal interval or physical distance between the first and second compared with the second an third stimuli) is varied. With an increase of the temporal interval there is an increase in perceived distance (Tau phenomenon) and, conversely, with an increase of physical distance, there is an increase in apparent duration (Kappa phenomenon). The congruency effect (impaired performance when motion signals move in conflicting, rather than congruent, directions) suggests that perceived direction of auditory motion can be profoundly affected by the direction of visual motion, yet only when the motion signals share common paths and are presented at the same time. Thus, spatial and temporal coincidence plays a critical role in multisensory integration (SOTO-FARACO, RONALD & SPENCE, 2004).

The significance of experience with different movements and positions is a topic focused on by various researchers. In the area of body tilt perception KAPTEIN AND VAN GISBERGEN (2004) make an interesting remark about unfamiliar body positions larger than 90° roll tilt; they suggest that spatial perception in these positions are carried out by a different mechanism than during small body tilts. They suggest that here more cognitive processes are involved.

"Vestibular Imagery"

DECETY, JEANNEROD AND PRABLANC (1989) found no differences between walking-time of a distance of 5m, 10m or 15m physically and in *imagining* the same except when they placed a weight of 25kg on the shoulders and asked the participants to carry it while actually walking or to imagine walking to the target distance. In the latter case, the participants produced longer walking-times which show the influence of subjective intuitive physics on time estimates when moving in space.

OZEL, LARUE AND DOSSEVILE (2004) also found a strong correlation (r = .80) between mentally imagining and actually walking to a seen target. The authors similarly reported significantly longer times for the imagery condition compared to the actual walking condition. OZEL ET AL. report an effect of unpleasant noise on mental imagery tasks (walking or imagine walking) and mental timing and stated that "the shared decrease in time performance in all tasks is the major argument supporting the implication of common timing mechanisms such as an internal clock" (2004, p. 202). It seems as if imagery shows similar effects as the actual walking conditions even though estimations are generally longer in the imagery condition, indicating higher involvement of attention and other cognitive factors.

The Cerebellum; Centre for Timing and Vestibular Signals?

The cerebellum can be conceptualized as a relatively task-independent timing mechanism which is restricted range from a few milliseconds to a few seconds (CLARKE, ET AL. 1996). For larger intervals, cognitive processes (e.g. attention and memory) become more relevant (IVRY & SPENCER, 2004A). Patients with cerebellar lesions show increased variability on temporal production tasks such as rhythmic tapping, or during the production of isolated movements with a specified target duration (SPENCER ET AL., 2003) which speaks for the significance of the cerebellum in the processing of time (see Figure 2). Interestingly, these patients are unimpaired when the periodic movements are smooth and continuous and the task involves discontinuities. The role of cerebellum in explicit timing and its relationship to other psychological processes was also investigated by

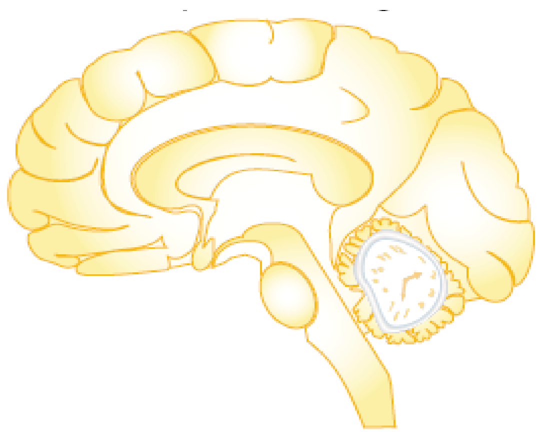

Figure 2 Is the cerebellum specialized for timing tasks? (IVRY & SPENCER, 2004A)

HARRINGTON ET AL. (2004). The authors hypothesize that if the cerebellum regulates timekeeping operations then cerebellar damage (caused by stroke) should disrupt the perception and the reproduction of intervals, since both are thought to be supported by a timekeeper mechanism. They found that patients with focal cerebellar lesions from stroke perform similarly to control participants on time production and perception tasks. IVRY AND SPENCER (2004B) criticize that HARRINGTON ET AL. (2004) failed to consider that patients with a chronic focal lesion (patients were tested on average 3.6 years after their stroke) tend to perform similar to control participants and also failed to observe consistent increased temporal variability on production or perception tasks. Furthermore, the interpretation of impaired performance on a single task is ambiguous, given the engagement of various component operations (such as the accurate representation of a stimulus duration, sustained attention and decision processes that compare the temporal representation with an internalized reference memory). A functional characterization of a neural system requires the integration of a wide range of tasks and the cerebellum is best conceptualized as forming a system of multiple timing elements rather than a single amodal "clock". IVRY AND SPENCER (2004A) believe that the cerebellum is clearly associated with various tasks that require precise timing. It provides representation of the precise timing of salient events, the onset and offset of movements or the duration of a stimulus. This is in line with neuroimaging literature where cerebellum is engaged during tasks requiring the precise representation of temporal information. This includes motor sequence learning, rhythmic tapping, duration discrimination, phoneme perception, and attentional anticipation. The authors suggest that subregions within the cerebellar cortex are recruited for timing in a task-dependent manner (IVRY, 1996) and emphasize a general computational principle of the cerebellum. IVRY AND SPENCER (2004A) furthermore discuss the role of the basal ganglia as a specialized timing system, especially for long intervals. Results of imaging and lesion studies in timing short intervals are ambiguous. The basal ganglia have been hypothesized to be a crucial component of the pacemaker/accumulator process. Dopaminergic agents lead to a systematic distortion of timed responses where agonists and antagonists lead to a shortening and lengthening, respectively, of perceived time (IVRY & SPENCER, 2004A).

Based on the fact that vestibular information and time-relative processing feed on the same structure, namely the cerebellum, I aim at investigating how strongly these two mechanisms interfere with each other.

Experiments

The first three experiments deal with "*Influence of perception on cognition*". The experiments are situated in the field of basic research on time production during vestibular stimulation. This study was inspired by previous research that suggested an influence of vestibular stimulation (rotation among the YAW-axis (z)) on distance and time perception (ISRAËL ET AL, 2004) and aimed at testing and reassessing the effect of higher velocities on time productions during prolonged stimulation of the semicircular canals (EXP ACC-DEC) or during minor constant roll movement activating only otoliths (EXP ROLL and EXP POS).

1.2. Influence of Vestibular Stimulation on Time Production

Abstract

Three experiments were conducted to test the influence of passive vestibular stimulation on time production. In EXP ACC-DEC (strong vestibular stimulation about the YAW-axis) 13 participants continuously produced given time intervals (1s, 8s, and 15s) in four different conditions (no stimulation, strong acceleration/deceleration, imagery of preceding perceptual condition). In EXP ROLL (otolith stimulation – constant roll) 15 participants produced time intervals while being rotated in the roll plane with low velocity (1.96°/s, exclusive otolith stimulation) at a constant velocity. In EXP POS (otolith stimulation – static positions) the same participants as in EXP POS were tested in static roll positions (90°, 135°, 180°, providing a constant otolith signal). In EXP ROLL and EXP POS participants continuously produced 1s, 3s, and 8s intervals. In EXP ACC-DEC the acceleration and deceleration conditions produced different slopes in line with the prediction; interval productions are accelerated in the course of time during acceleration and intervals become continuously shorter during deceleration. In EXP ROLL and EXP POS, vestibular stimulation was reduced to mere otolith stimulation. No influence of was found in EXP ROLL but durations of produced intervals did significantly increase when participants conducted the task in roll positions 90° and 135° compared to the upright position. Concurrent vestibular stimulation seems to slow down short interval productions; this can be explained with increased cognitive load and with interfering processing of timing and vestibular information in the cerebellum.

Introduction

Recent research (ISRAËL ET AL., 2004) gave rise for this work. The authors found a relationship between time perception and vestibular input by assessing time perception without providing any visual information. The authors suggest that analogue to time perception, distance perception is altered during vestibular stimulation. In their experiment participants are seated on a "robot" and are exposed to different movement patterns: a linear forward movement, a rotation about body axis (acceleration or deceleration - $5°/s^2$ - in the yaw axis), and no movement. In the experiment, participants are asked to press a button every second. The authors showed that the length of produced intervals or standard deviations did not vary systematically. Yet, a slope analysis[3] revealed that in the linear constant velocity motion the slopes decreased (intervals are progressively produced shorter in the course of time) with higher velocities ($p < .05$). This was not the case in the rotation trials with constant velocities, where the velocity had no influence. In the accelerated trials, the slopes for the acceleration were lower than the slopes of the deceleration, in both the

[3] Measurement of steepness of the continuous interval productions; If the slope is higher than 0, the participants increased the inter-press interval (IPI) in the course of the experiment. If the slope is less than 0, the participants decreased the IPI.

linear motion (except backwards) and the rotation. Interestingly, negative slopes became more negative and positive slopes more positive the faster motion of the robot (10°/s, 35°/s, 60°/s). The following experiment was also conducted to validate the results of ISRAËL ET AL. (2004) with stronger acceleration and higher velocity and by adding the imagery condition.

Judgments of the elapsed time for intervals of multiple seconds is attention mediated (BLOCK & ZAKAY, 1997), or what has been called cognitive timing (LEWIS & MIALL, 2003). How "cognitively" are different time intervals processed and influenced by vestibular stimulation? Can the perception of and attention to task-irrelevant movement actually be "shut out" during time production?

The aim of the three experiments described here is to enlighten the relative contributions of vestibular stimulation to the cognitive process of time perception. Can time processing in time production tasks be conducted independently from vestibular stimulation (and other accompanying inputs such as blood pressure on brain or somatosensory input) if it is task-irrelevant? Furthermore, the relative role of vestibular signals – semicircular canal activation vs. otolith activation – is investigated. In the first experiment, strong vestibular signals are imposed on participants while they are asked to continuously produce time intervals (EXP ACC-DEC). No distinction between semicircular canals and otoliths is made, while the following experiments (EXP ROLL and EXP POS) focus on mere otolith stimulation by shutting out semicircular stimulation; this is reached by using constant velocity or static roll positions below the threshold of the semicircular canals. In EXP ROLL and POS, the aim is to assess the effect of continuous and passive roll movement (known to trigger different interpretations of movement) and tilt magnitude on time production. In EXP POS specifically investigates if the spatial disorientation experienced in positions larger than 90° results in altered mental activity and thereby influence time productions. According to KAPTEIN AND VAN GISBERGEN (2004), cognitive processes are suggested to become more involved in positions larger than 90° where perceived body tilt seems to be computed with the additional input of a cognitive variable that competes against the otolith input. Could triggering of such cognitive processes affect additional cognitive processes such as time production? We hypothesize that the proposed switching of strategy (KAPTEIN & VAN GISBERGEN, 2004) at the same time leads to increased cognitive load (similar to a dual-task situation) affecting time productions. This should manifest itself in a slowing down of subjectively perceived time and a higher variation (ZAKAY & BLOCK, 2004). Furthermore, the timing system might also be affected (slowing down) because vestibular information is feeding on the same structure that is responsible for timing functions; the cerebellum.

Experiment ACC-DEC: Strong vestibular stimulation

EXP ACC-DEC investigates the effect of strong vestibular stimulation – acceleration, deceleration or imagery of the concurrent condition – on time productions. Based on previous studies (e.g. ISRAËL ET AL. 2004), strong vestibular stimulation is expected to alter time production.

Arousal theories would predict that the resulting arousal leads to a general acceleration of the internal clock. The incremented physical level causes more time pulses to be transmitted to a cognitive counter and should result to an over-estimation of perceived time (OZEL ET AL., 2004). Time intervals therefore should be produced shorter than in a baseline condition where participants can fulfill the time production task at a low activation level. However, theories further considering *attentional resources* and *cognitive demands* of the task (e.g. THOMAS & WEAVER, 1975; ZAKAY & BLOCK, 2004) predict that if a concurrent nontemporal task is demanding, fewer attentional resources are available to allocate to temporal information processing. This leads to fewer time signals to accumulate in the cognitive counter and to less reliable processing of time. Produced intervals should accordingly be increased in the experimental conditions and standard deviations should be augmented.

Based on the assumption that time and vestibular signals are both processed by the *cerebellum*, it is suggested that the strong vestibular stimulation applied interferes with time processing. We suggest, that the internal clock is accelerated when participants are being accelerated and decelerated when they are decelerated about. This should lead to intervals becoming progressively shorter during the acceleration condition and progressively longer in the deceleration condition.

An imagery condition is added to investigate if the effects correspond with the according perceptive condition. Furthermore, the task to imagine acceleration and deceleration represents an even further increase of cognitive load which should lead to produced intervals to increase. As mentioned in the introduction, imagery has been shown to lead to an over-estimation of distance (OZEL ET AL., 2004). GLASAUER (2007) further found that participants overshot distances at higher velocities and undershot them at slow velocities.

Method

Participants

Thirteen healthy volunteers (5 female, mean age 29.4 years, range 24-39 years) participated in the experiment. All participants were naïve with regard to the hypothesis under investigation. They all gave their informed consent to the experimental procedure. Two subjects (1 female, 1 male) had to be excluded from analysis. One person felt sick and the other misunderstood the task.

Material and Procedure

Apparatus. The 3D-Turntable (Acutronic) of the University Hospital of Zurich, Department of Neurology, used for this experiment is driven by three servo-controlled motorized axes, controlled with Acutrol ®. Rotations of the inner rotary frame turn the sitting subject about his/her longitudinal YAW axis (=z-axis, see Figure 3). The participants are comfortably seated in an upright position and are fastened in a padded seat secured with a 5-point-belt. The feet rest safely in a foot support. The legs are restrained at the height of the ankles. An individually matched mask securely keeps the head at a steady position in the center of rotation. A laptop and response key to produce the intervals (standard keyboard) is mounted in front of the participant. The instructions are given before the experiment but are also shown on the laptop screen in front of the participant (see Figure 3). The velocity profile applied for this

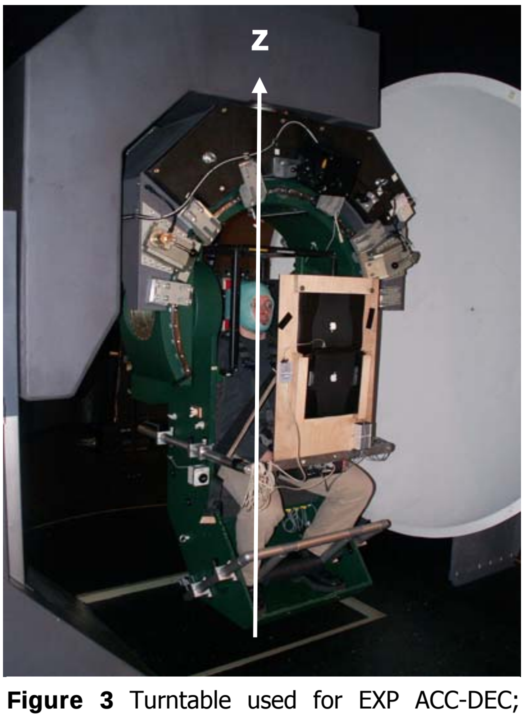

Figure 3 Turntable used for EXP ACC-DEC; Semicircular canal stimulation is delivered by on-axis angular rotation about an earth-vertical axis.

experiment is visible in Figure 4. The application of yaw-rotation leads to largest activation of the horizontal canal, slightly lower activation of the posterior canal and only minor activation of the anterior canal during rotation. The "efficiency" of canal stimulation is identical for the right and left sides. Depending on the direction of chair rotation, one side will produce an ON response and the other side will produce an OFF response, but the strength of the combined response depends on the canal efficiency; similarly for the posterior canal pairs (PAVLOU ET AL., 2003).

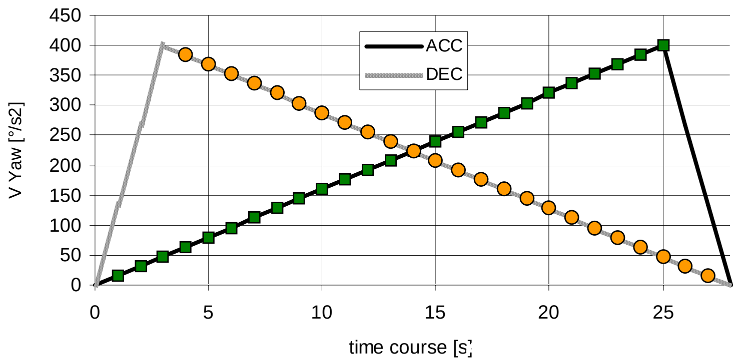

Figure 4 Velocity profile of the turntable for the two sessions ACC and DEC. Icons indicate the experimental phase (circles: time interval production started only after a fast acceleration to the maximum of 400m/s; squares: participants started acceleration of turntable with their first interval button press.

Task. Participants are to continuously produce time intervals (repetitive tapping task: 1s, 8s and 15s counterbalanced). Participants are asked to produce what they believe is 1s, 8s or 15s is and are not provided with a standard stimulus.

Experimental procedure. SESSIONS (ACC/DEC, within design) are counterbalanced and conducted within a few days (but never on the same day; factor ORDER: 1/2). After the participant is seated in the turntable and instructions are given that he/she continuously produce the all of the given intervals during 25s in 4 different CONDITIONS (also see Figure 5):

- Baseline with no vestibular stimulation
- Perception1 (ACC or DEC)
- Imagery (imagining preceding ACC or DEC)
- Perception 2 (ACC or DEC)

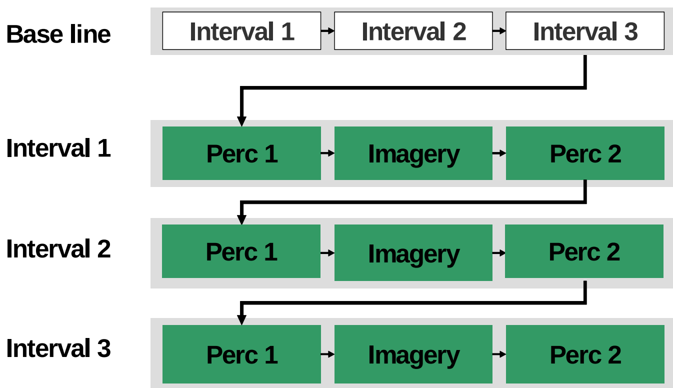

Figure 5 Experimental procedure: after Baseline condition participants produce intervals in experimental conditions in the same order as in baseline.

To ensure that the participants are ready to start the perception conditions they are asked to start the motion of the turntable with a button press when they are ready. For ACC the turntable begins at 0°/s accelerates with 16°/s^2 after the participants starts motion until it reaches the maximum velocity of 400°/s (see Figure 5). For DEC the turntable accelerates to 400° within about 3s and after maximal speed is reached, an acoustic signal indicates that participants are to start continuous interval production while the turntable linearly decreases velocity with 16°/s^2 for 25s to 0°/s.

Due to the 25s duration of the conditions the maximally possible amount of produced intervals is limited to: 20 intervals for the 1s interval, 3 intervals for the 8s interval and 2 intervals for the 15s interval. Yet, the amount of actually produced intervals varies strongly between participants.

Results and Discussion

Data exclusion criteria:

- The first interval production was excluded to allow participants to get accustomed to the task. However, due to the little amount of intervals for 8s and 15s this was only done for the 1s intervals.
- *Outliers*: For every person and every condition, interval productions larger than 2 standard deviations above or beneath the average were also excluded (1.8% of all data). This lead to an average of 17 interval productions per participant and condition for the 1s interval (ranging from 8 to 20 adjustments)
- Data of 15s and 8s interval productions were limited to the analysis of the average interval productions and have to be handled with caution due to the very low amount of productions collected for these intervals.
- F-values from ANOVAs lower than 1 ($F < 1$) were not interpreted because the variability within the conditions was higher than between conditions. A Greenhouse-Geisser correction was applied when Mauchly's W reached a significance level of $p < .05$.

Unfortunately the baseline condition was not assessed with all of the participants: one participant did not complete the 1s interval baseline and another only conducted baseline conditions before session ACC. This has to be considered when deviation from baseline is analyzed.

Subjective Reports

Participants generally described the first session to be more troublesome and that they felt a little sick the first time, independent of whether they started with the ACC or DEC session. Participants also reported strong post-rotatory effects[4]. This effect was different between the two conditions (post-rotatory phase starts during the deceleration phase in session DEC or after experimental phase has ended in session ACC). An additional difference of the two experimental conditions was the fact that the velocity profiles were not exactly opposite to each other.

During the experiments it turned out that imagery of acceleration and deceleration was quite a hard task. Only very few participants reported no problems, the majority found it impossible to imagine acceleration or deceleration and imagined constant movement instead.

Effect of Condition for the Three Intervals

There was no significant effect of ORDER in any of the intervals. This implies that there was no training effect even though participants felt that they perform "better" in the second session.

Analyses of variance (ANOVA) and individual t-tests (2-tailed) were conducted on average interval productions separately for all of the three intervals:

1s Interval

The 1s interval produced were too long ($p < .001$) in all of the conditions, on average this was 25%. Figure 6 shows average and standard deviation of 1s interval productions. Since not all per-

[4] The post-rotatory effect is known to diminish quite fast (lasting from 5s at first to 1s). This adaptation could possibly be a cognitive effect.

sons conducted a baseline the analysis of variance (ANOVA) is based on only 9 participants: A two-way ANOVA with repeated measures, with the within subject factors SESSION and CONDITION revealed a significant effect for the factor **CONDITION** ($F(1, 8) = 3.31$, MSE = 20284.992, $p < .05$, $\eta^2 = .116$). Bonferroni-corrected pairwise comparisons reveal a significant difference between the conditions **base-perc1** ($p < .05$). The factor SESSION did not reach significance ($p = .336$).

Comparison of Baseline (*base1* and *base2* grouped together) with experimental conditions ACC and DEC (*perc1* and *perc2* grouped together) reveals a significant effect for **ACC** ($p < .05$) but not for DEC.

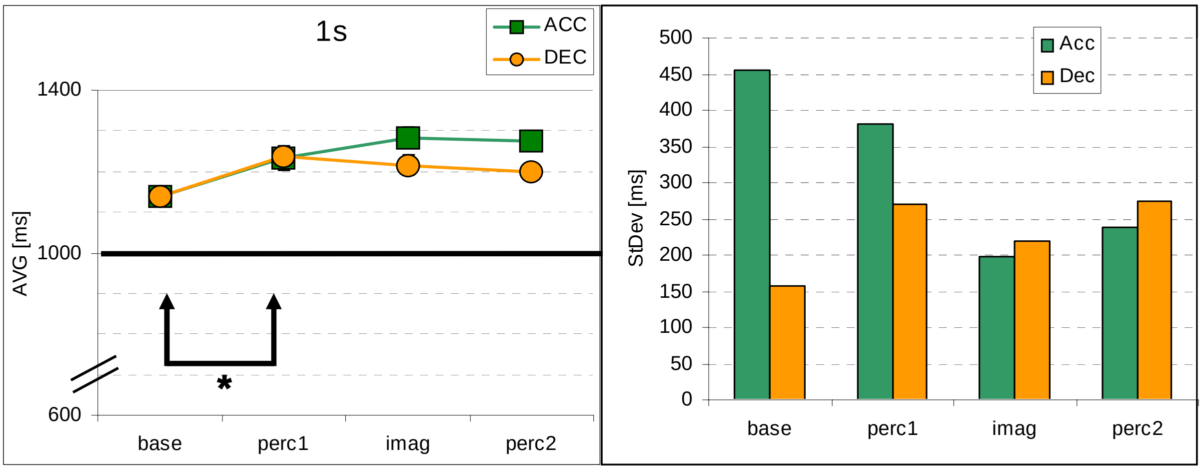

Figure 6 LEFT: Average interval productions and **RIGHT:** standard deviation for the 1s-interval shown for the experimental conditions baseline (base), perception1 (perc1), imagery (imag) and perception two (perc2). (N=10 except N=9 for baseline condition)

8s Interval

In line with the 1s interval, the produced 8s interval was on average too long ($p < .05$), yet this effect was smaller compared to the 1s interval (9%). A two-way analysis of variance (ANOVA) with repeated measures with the within factors SESSION and CONDITION revealed no significant effect for the average interval production (presumably due to large SD, see Figure 7) neither for the factor SESSION nor the factor CONDITION. However, Paired Samples t-Tests (2-tailed) of CONDITION (base, perc1, perc2 and imag) revealed a significant difference between **base-imag** for DEC ($p < .05$).

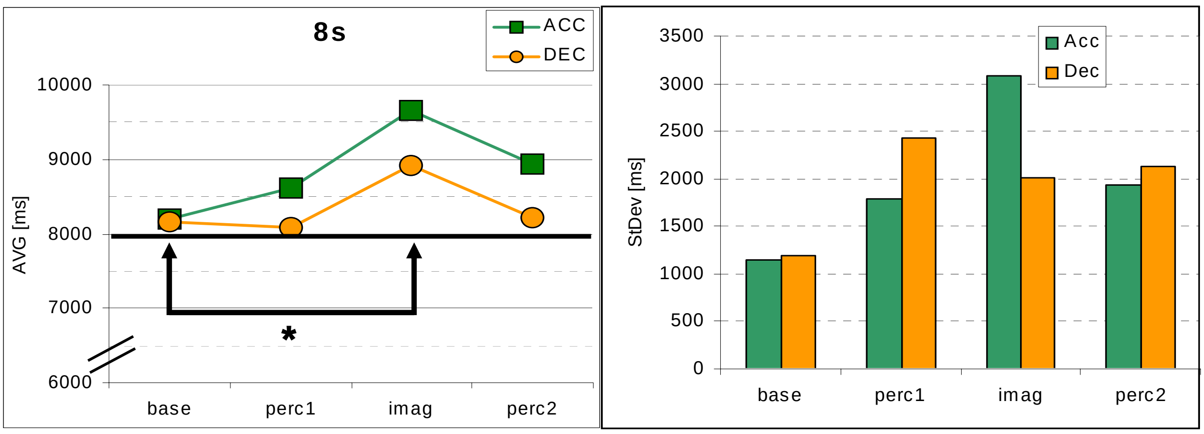

Figure 7 8s-interval: **LEFT:** average interval productions and **RIGHT:** standard deviation (N=11)

15s Interval

In line with the other two intervals, the 15s interval was on average produced too long ($p < .05$), this over-estimation was comparable to the 8s interval (10%). A two-way analysis of variance (ANOVA) with repeated measures with the within factors SESSION and CONDITION revealed no significant effect for the average interval productions (presumably due to large SD). Paired Samples t-Tests (2-tailed) of CONDITION however revealed a significant difference between **base-imag** for ACC and between **perc1-imag** for DEC (both $p < .05$, see Figure 8).

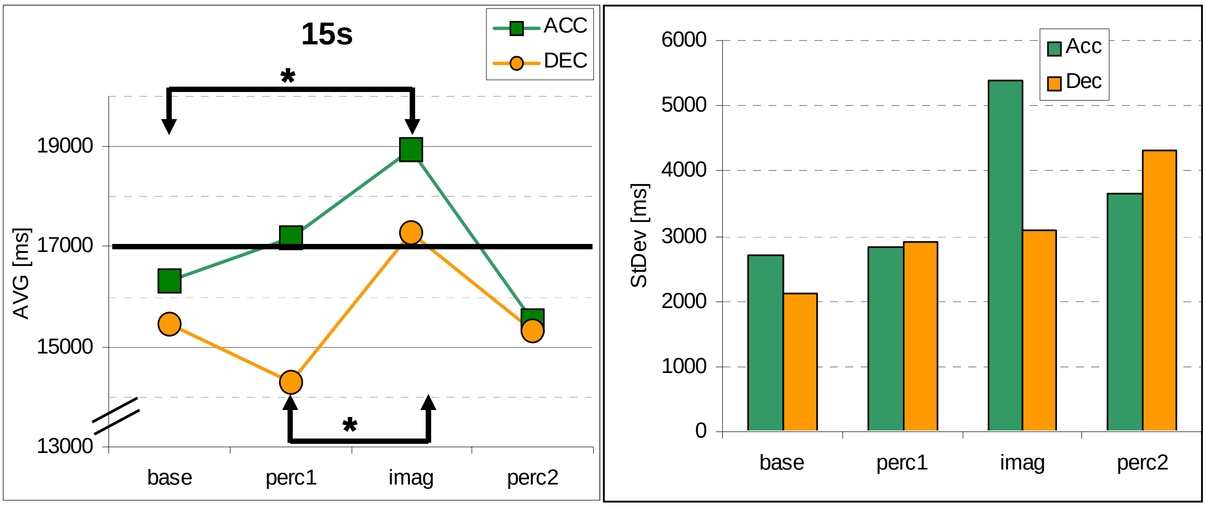

Figure 8 15s interval: **LEFT:** average interval productions and **RIGHT:** standard deviation (N=11)

Comparison of average interval productions in ACC and DEC (*perc1* and *perc2* grouped together) revealed a significant effect of **SESSION** ($p < .05$).

The effects found were quite ambiguous. While all of the intervals were significantly produced too long, the different conditions did not systematically change time productions.

For the 1s interval there was a significant effect of condition, revealing a significant increase of produced intervals from the baseline condition to the first perception condition; however this was independent of whether the baseline was followed by the deceleration condition or the acceleration condition. Post-hoc analyses showed that only when perc1 and perc2 are averaged, ACC differed significantly from the baseline while DEC did not. Inspection of Figure 6 shows that on average, produced time intervals were increased for ACC.

For the longer intervals 8s and 15s significant effects emerged in the imagery conditions. Average interval productions in the imagery condition were significantly longer than in the baseline condition, yet while this effect emerged only in the DEC SESSION for the 8s interval, the same effect appeared only in the ACC SESSION for the 15s interval. Furthermore, in the produced 15s intervals the imagery condition were also significantly longer than in the perc1 condition. In the 15s interval there was a significant difference between the SESSIONS; produced intervals in ACC were significantly longer compared to those produced during DEC. This is in the same direction with what we found for the 1s interval where the experimental condition ACC differed significantly from the baseline condition.

Because there were pronounced individual differences we decided to perform further analyses on normalized data where interval productions were considered relative to the according individual baseline 1.

Normalized Data

To eliminate individual level differences of interval production normalized data were calculated. This resulted in the percentage of deviation from the corresponding baseline1 as is seen in Figure 9.

Even though Figure 9 shows increased interval productions relative to the baseline for ACC compared to DEC, a two-way analysis of variance (ANOVA) with repeated measures, with the within subject factors SESSION and CONDITION calculated separately for the three tested intervals yielded no significant effects for the 1s and the 8s interval. There was a significant effect of the factor **SESSION** for the 15s interval ($F(1,7) = 6.26$, MSE = 0.017, $p < .05$, $\eta^2 = .472$). Paired Samples t-Tests (2-tailed) conducted to compare CONDITION revealed a significant difference between **perc1-imag** only for the 15s interval ($p < .05$).

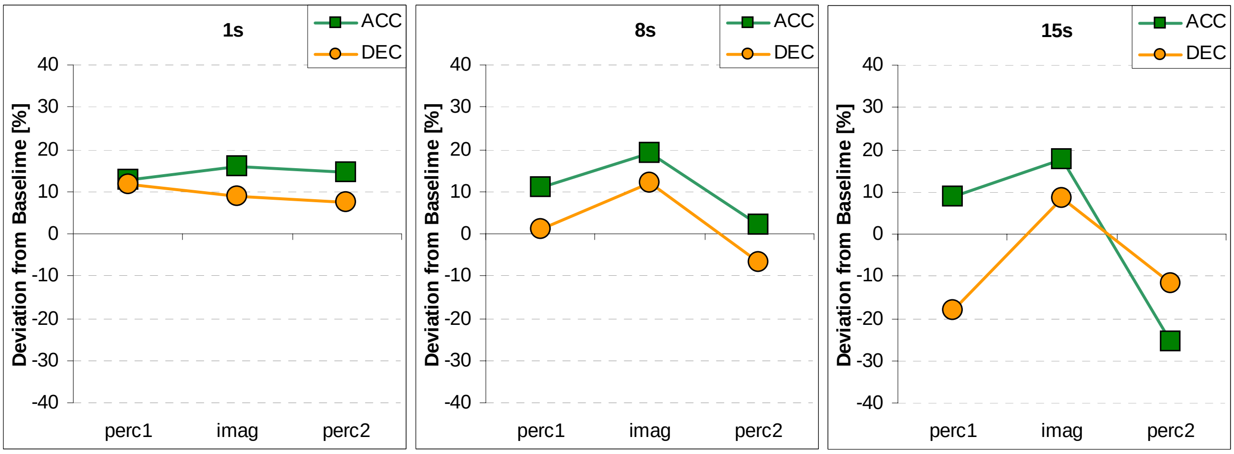

Figure 9 Normalized data for the three intervals showing that – with exception of the perc2 of the 8s-interval and the 15s interval - productions are generally longer in the experimental conditions compared to the individual baselines.

The analysis of normalized data showed no effect of condition or session for the 1s and 8s interval. The effect found for the 15s interval again shows that interval productions during ACC were increased compared to DEC. Furthermore, as was found for the analysis of average interval productions, imagery again showed increased values compared to the first perception condition.

Slope Analysis

Slope analysis can reveal a change of produced interval durations in the course of time in the different conditions or between the two sessions tested. To compute the slope, a linear regression is fitted through the data points of each individual and condition; this is done applying the following formula:

$$b = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sum (x - \bar{x})^2}$$

where x are the given interval production values and y corresponds to the counter of the intervals.

The slope analysis was only conducted for the 1s interval because the amount of intervals was too little in the other time interval conditions.

A two-way analysis of variance (ANOVA) with repeated measures, with the within subject factors SESSION (ACC, DEC) and CONDITION revealed a significant effect for the factor **SESSION** $F(1,8) = 8.49$, MSE = 54.365, $p < .05$, $\eta^2 = .515$). An examination of individual slopes showed that 8 out of 10 participants produced higher slopes for DEC which are always positive (intervals get longer) compared to ACC where slopes tend to be negative (with two exceptions), suggesting that produced intervals get shorter in the course of time. There was also a significant effect of the factor **CONDITION** $F(3, 24) = 5.02$, MSE = 44.697, $p < .01$, $\eta^2 = .386$. Bonferroni-corrected pairwise comparisons revealed a significant difference between the conditions **perc1-imag** ($p < .05$); the comparison of perc1-base nearly reached significance with $p = .065$. This result is also clearly visible in Figure 10 where perc1 and perc2 were averaged and allow a direct comparison of the average ACC and DEC slopes.

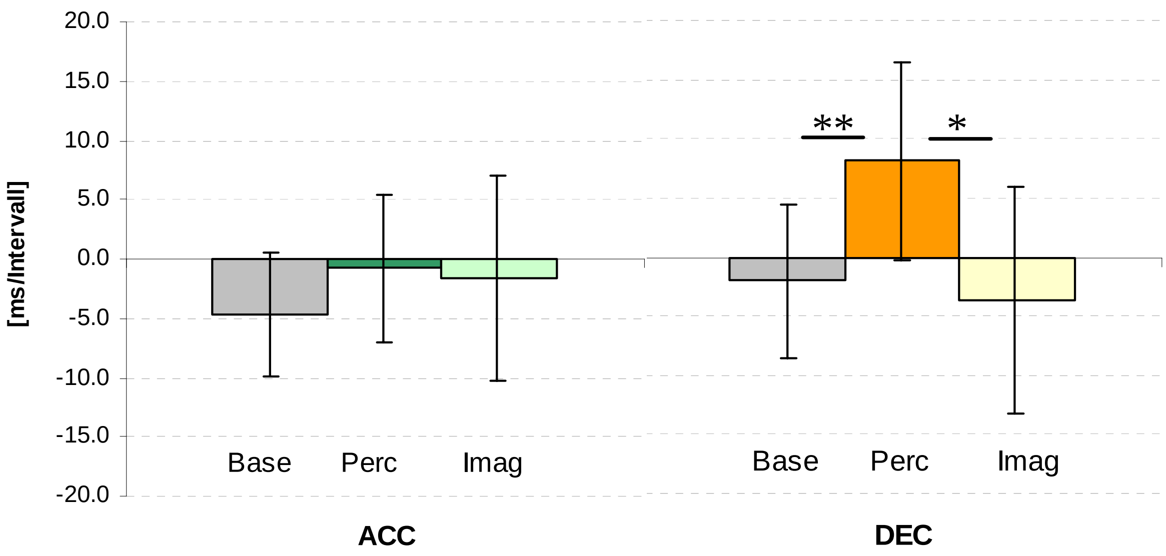

Figure 10 1s interval: Slopes averaged over participants (average of perc1 and perc2 = Perc). **LEFT:** ACC SESSION, **RIGHT:** DEC SESSION

A separate analysis of variance (ANOVA) with repeated measures conducted separately for the two sessions acceleration and deceleration revealed no significant effect of CONDITION for ACC, but the effect was nearly significant for DEC with $F(1.49, 13.39) = 3.92$, $p = .056$, $\eta^2 = .303$. There was no significant interaction of SESSION*CONDITION ($p = .544$).

There is no doubt that the kind of vestibular stimulation applied is very strong and is accompanied by increased general arousal. The demanding task of time production however opposes to the initial hypothesis that this arousal should lead to a general decrease of produced intervals. More so, as discussed in the introduction, increased cognitive demands should result in a decrease of experienced duration and to lengthened interval productions the longer the interval to be produced. Furthermore a higher variation was to be expected which shows clearly for the longer intervals 8s and 15s (see right side of Figure 7).

Analyses of average interval productions revealed that effects showed a general increase especially for the acceleration condition. Productions were also comparatively longer during imagery, sometimes compared to the baseline condition (DEC, 8s; ACC 15s) and sometimes even compared to the perc1 condition (DEC, 15s). This could imply that the longer the interval to be produced, the stronger the effect of slowing down during increased mental load.

The two sessions were expected to differ due to interaction of time and vestibular processing in the cerebellum especially for the 1s interval which is supposed to be more automatically processed (LEWIS & MIALL, 2003). We did indeed find that slopes of produced intervals were significantly different in the two sessions acceleration and deceleration. Intervals on average started off long and tended to get shorter in the course of time during acceleration opposed to the deceleration condition where intervals started off long and got significantly longer in the course of time (see Figure 11). As mentioned before, it can not be ruled out the velocity profile being not exactly opposite, and different concurrent postrotatory effects in the two conditions could have lead to the different results.

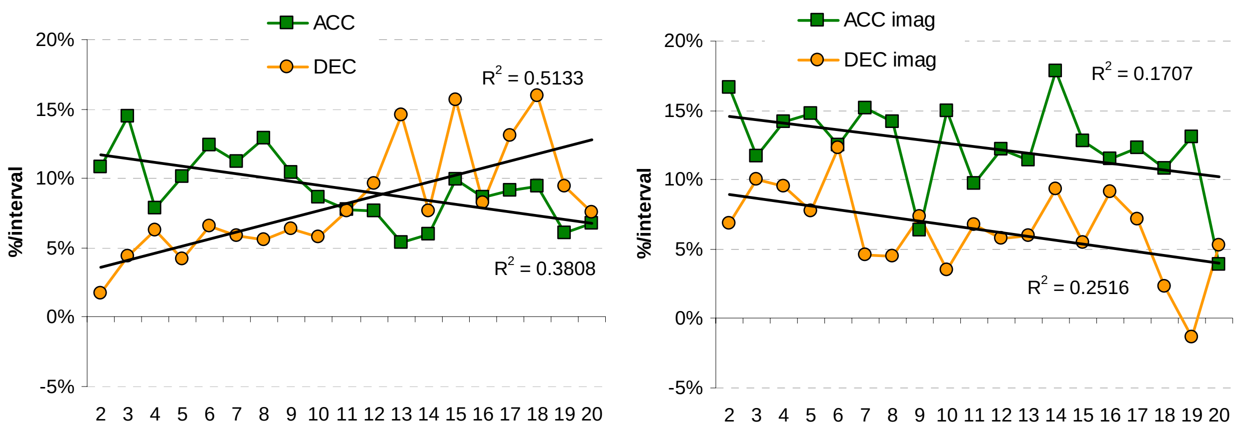

Figure 11 Slopes shown for the experimental conditions ACC and DEC (**LEFT**) and for the according imagery conditions (**RIGHT**) for the 1s interval: Here every interval is deducted from the baseline condition, X-axis: number of intervals. Y-axis: deviation from individual baseline (1 and 2 taken together). (N=10)

As mentioned in the introduction, imagery has been shown to evoke similar effects in a walking condition but usually shows a general increase of estimations. This has been interpreted as a result of higher involvement of attention and other cognitive factors. Furthermore, the results of distance estimations with high velocities (GLASAUER, 2007; MITTELSTAEDT & MITTELSTAEDT, 2001) showed that participants tend to overshoot targets. In our experiment, imagery did not show the same effect as the corresponding perceptual condition (see Figure 11); results rather indicate that independent from session, intervals here were produced comparably too long (as seen for distance estimations at high velocity) and they tend to get shorter in the course of time[5] similar to the effect noticed for the acceleration condition.

Both experimental conditions were expected to differ significantly from the baseline condition, however, regarding average interval productions this is only true for the 1s interval where intervals increase from baseline1 to the perception1 condition. An important difference to the reproduction of a previously presented time interval is that in the task here, participants are to produce an acquired notion of time units. I suggest that this resulted in an increased cognitive involvement and lead to the fact that all of the intervals were produced too long.

[5] It needs to be considered that the number of produced intervals is not equivalent for all participants.

Experiment ROLL (Constant Roll) and POS (Static Roll Positions): Otolith Stimulation

It is known that pure otolith stimulation by a continuously rotating linear acceleration vector produces a variety of perceived movements, including angular rotations, as in off-vertical axis rotation (BENSON, DIAZ, FARRUGIA, 1975; DENISE ET AL. 1988; GUEDRY, 1974), in the 'barbecue spit' rotation (BENSON & BODIN, 1966; MITTELSTAEDT ET AL. 1989), or in counter-rotation on a centrifuge (BENSON, 1974). In off-vertical axis rotations, the direction of gravity is available as an important directional cue. Tracking self-orientation is known to result in a quite appropriate estimation of changes of body orientation up to 200 deg (for review, see YOUNG, 1984). KAPTEIN AND VAN GISBERGEN (2004) however suggest a change of strategy for body positions exceeding 90° and also a stronger involvement of cognitive factors (possibly to resolve the perceptual "confusion" confronted with). In order to separate the specific contribution of the otoliths (as well as the unavoidable tactile information of pressure and friction) from visual and semicircular cues, participants are passively moved with under-threshold velocity for semicircular canals (1.96°/s) at constant velocity about the x-axis (EXP ROLL) or positioned in static roll positions in absolute darkness (EXP POS). As mentioned in the introduction, increased arousal is supposed to lead to an acceleration of the internal clock (OZEL ET AL., 2004). ZAKAY AND BLOCK (2004) however find that when the degree of cognitive demand is considered time estimations are increased because fewer time signals accumulate in the cognitive counter when attention is being shared. According to ZAKAY AND BLOCK (2004) the more demanding the concurring nontemporal task, the fewer attentional resources are available to allocate to temporal information processing. They find that prospective estimates made immediately after a duration increased if the processing task was easier, whereas retrospective estimates were unaffected by processing difficulty. Also, according to THOMAS AND WEAVER (1975) less attention to time leads to diminished and less reliable processing of time information.

Similar to the previous experiment vestibular stimulation is suggested to interfere with time production. Passive transportation (EXP ROLL), as well as prolonged lingering in unusual positions (EXP POS) results in a kind of dual-task situation where the processing of perception of movement or body position and the processing of time will draw on the same limited resource, the cerebellum.

Based on the previous findings and theoretical predictions, produced intervals in the experimental conditions should be increased compared to the baseline condition. Especially intervals produced during unfamiliar and confusing large body tilts (larger than 90°) are supposed to be increased because of increased cognitive demands. The resulting decreased attention to time leads to diminished and less reliable processing of time information which should show in increased standard deviations especially for longer intervals.

Method

Participants

Fifteen healthy volunteers (8 female, mean age 25.4, range 19-36) gave informed consent to the experimental procedure and participated in both experiments. All participants were naïve with regard to the hypothesis under investigation. Data of one participant (female) was excluded because she wasn't feeling well and had to abort the experiment leading to 14 participants to enter analysis.

Material and Procedure

Apparatus. The 3D human turntable (see Figure 12) at the Department of General Psychology, Zurich, used for these experiments is driven by three servo-controlled motorized axes. The ax needed for this paradigm was moved at a constant angular velocity of 1.96°/s for the roll plane rotation. Buttons inside the cockpit (attached to the right side of the helmet) allow participants to continuously produce the given time intervals.

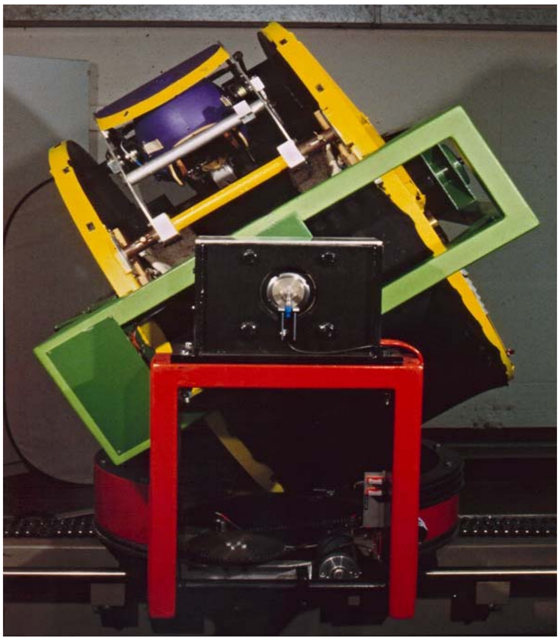

Figure 12 Human turntable used for EXP ROLL and EXP POS

Task. Participants are asked to press a button attached to the right side of their helmet every 1s, 3s or 8s (repetitive tapping task) either with no motion (baseline) in a fully upright position (0°) or in:

- EXP ROLL: during constant roll movement (360°) or in
- EXP POS: in 3 roll positions (90°, 135°, 180°).

The succession of intervals is counterbalanced between the participants. The order of intervals in the first experiment however remains the same in the second for every participant. The factor DIRECTION (leftward or rightward) is balanced within the participants and also remains the same for the participants in the two experiments.

Experimental procedure (see Figure 13). Participants were comfortably seated inside the cockpit of the human turntable and fastened with inflatable cushions that were molded to the sides of the upper body and legs. Their head was secured in a helmet. After being firmly fastened into the cockpit and the light was switched off, the participant was slowly moved to a fully upright starting position. As soon as the human turntable came to a firm stop participants started producing intervals in a baseline condition. Then,

- In EXP ROLL (constant roll) the human turntable started a continuous roll movement after the participants pressed a button to signal they were ready to roll. The constant velocity of 1.96°/s resulted in an absent or minor stimulation of the semicircular canals and a constantly changing stimulation of the otolith organs. As soon as the movement started participants were asked to start interval production until the machine stopped (after rotating 400°, from 350-10° if rotated clockwise or from 10° to 350° when rotated counterclockwise) resulting in a final position mirrored to the starting position[6]. Then, another baseline condition followed

[6] The human turntable started at 350° (10° respectively) and stopped at 10° (350° respectively) in EXP ROLL to allow analysis of time intervals produced throughout the entire 360° rotation. Intervals produced between 350°-360° and between 360°-10° were excluded)

(unfortunately only 8 out of 15 participants conducted this condition), see left side of Figure 13.

- In the following EXP POS (static positions), conducted with the same participants as in EXP ROLL, the inputs of semicircular canals were shut out by tilting the participants to fixed roll-positions. Before participants started interval production they were to wait a few seconds to assure they felt no more movement (to rule out influence of semicircular canals). After every position participants were moved back to the upright position (shortest way) and after a short break (length determined by participant) the interval production in the next position followed. After conclusion of the experimental conditions a second baseline condition was conducted (for all participants) (see right side of Figure 13).

Both experiments last about 50min each.

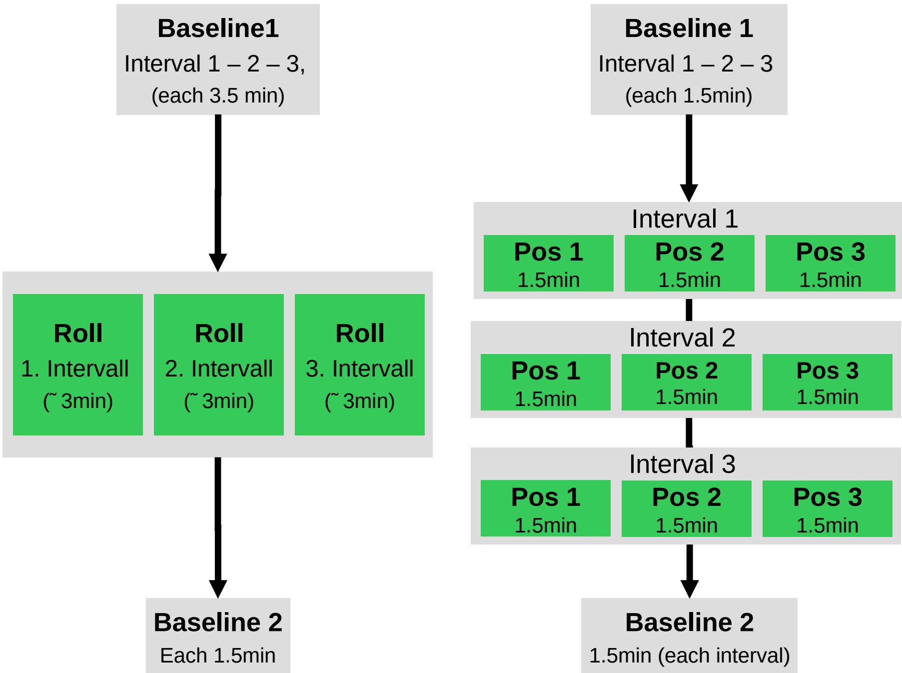

Figure 13 Experimental procedure for **LEFT:** EXP ROLL and **RIGHT:** EXP POS.

Results and Discussion

Data exclusion criteria:

- First 5s (of 1s interval production) or 1st adjustment (for 3s and 8s interval production, separately for all conditions) were not considered in analysis.
- *Outliers*: As in the previous experiment, productions that were 2 standard deviations over- or underneath the conditions average (per participant) were excluded (3.98% of all data). Also, for the 3s interval, productions smaller than 1s and larger than 8s were not considered (0.03%). For the 8s interval, productions lower than 4s and larger than 17s are excluded (0.11%).
- EXP ROLL: only intervals between 0°-360° were recorded during the experimental procedure, however, since this lead to quite a different amount of given productions per

participant and to allow comparison of different participants, the *amount of analyzed intervals was limited* to:

    - 1s: 140 for base1, 120 for ROLL (30 per sector[7]) and 70 for base2
    - 3s: 40 for base1, 40 for ROLL (10 per sector) 20 for base2
    - 8s: 20 for base1, 20 for ROLL (5 per sector) 10 for base2
- EXP POS: for the same reasons the amount of analyzed interval productions was limited to:
    - 1s: 70 for base1, base 2 and for each roll position (90°, 135°, 180°)
    - 3s: 30 for each of the conditions
    - 8s: 10 for each of the conditions
- F-values from ANOVAs lower than 1 ($F < 1$) were not interpreted because the variability within the conditions is higher than between conditions. A Greenhouse-Geisser correction was applied when Mauchly's W reached a significance level of $p < .05$.

Results are first presented separately for the two experiments. Comparison and discussion of both follows further down.

Experiment ROLL

Subjective Reports

Roll movement was experienced and described differently by the participants. Some reported feeling being rotated about the shoulder (correct), rotation about the shoulder with concurrent forward tilting, rotation about the shoulder with simultaneous backward tilting, faster downwards tilting and slower upward tilting, rotation about the shoulder and simultaneous downward sinking and different roll movements in different conditions.

Effect of intervals

Generally, intervals were produced too long in all of the conditions, however this was again most strongly the case for the 1s interval where the estimated interval was 46% longer compared to objective time. The over-estimation of the intervals decreased to an average of 28% for the 3s interval and to 18% for the 8s interval (also see Table 1 further down for a more detailed overview).

Effect of Experimental Conditions/ Tilt Magnitude

Analyses of individual intervals are presented individually. No significant difference between directions of rotation (7 participants each) was found and left and right roll direction data were therefore analyzed together.

[7] Roll rotation was split in to 4 sections: 0-89°, 90-179°, 180-269°, 270-359° (also considered as large (90-270°) and small (270-90°) body tilts (see Figure 14)

To allow a closer look at the effect of tilt magnitude, an analysis was conducted based on different tilt sectors (1-4 see Figure 14). Furthermore, to evaluate the effect of large body tilt the 360° were divided into small tilt sections (0-90° and 270-360°, sectors 1+4) and a large tilt section (90°-270°, sectors 2+3). Paired Samples t-Tests (2-tailed) are conducted for the following comparisons of conditions: BASE1-BASE2, BASE1 and BASE2 compared to: ROLL (average of all sectors), each sector individually and finally to small tilt (SECT1and SECT4) and large tilt (SECT2 and SECT3).

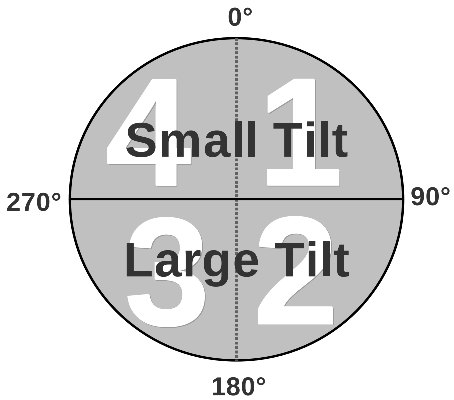

Figure 14 Sectors and Division between Small and Large Tilts used for analysis

1s Interval

Inspection of Figure 15 shows that there was quite a difference of individual estimation of 1s intervals ranging from 806ms to 2897. This is due to the fact that no "standard" was provided to the participants (also see discussion further down) and individual concepts of 1s obviously vary greatly.

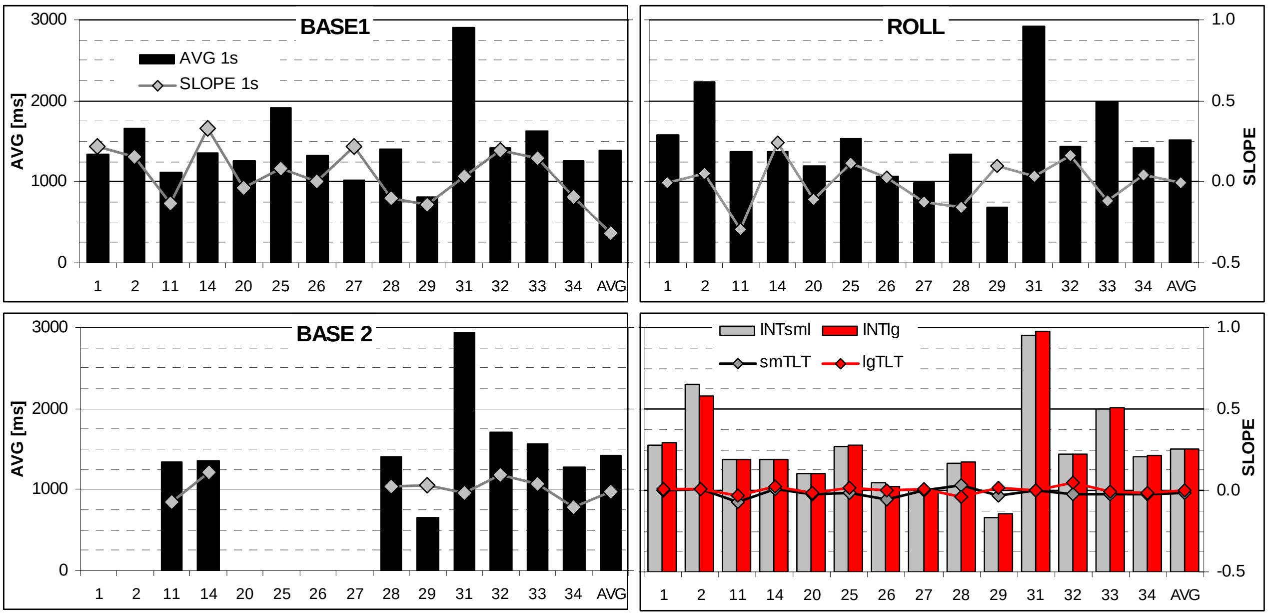

Figure 15 1s-Interval: Individual data given for the baseline conditions **(LEFT:** BASE1 and BASE2**)** and the experimental condition **(RIGHT:** ROLL**)** for averaged data **(RIGHT TOP)** and data split to the small- and large tilt areas **(RIGHT BOTTOM).** The left axis refers to the average interval production and the right to the average slope calculation. (N=14)

Average Interval Productions and Slopes. Paired Samples t-Tests (2-tailed) revealed no significant differences of condition for any of the comparisons for average interval productions (all p>.351) or average slope calculations (all p>.059).

Standard Deviations. There were significant differences between **BASE1-SECT1** (t(13) 2.72, p < .05) and between **BASE1-SECT2** (t(13) = 3.06, p < .01). The comparison BASE1-smTLT did not quite reach significance with *t*(13) = 1.85, *p* = .088. In all of the cases standard deviations were higher for baseline1 than in the compared sectors.

The significant improvement of consistency speaks in favor of a training effect in people "finding" their "tact". The results did not show a systematic effect of condition and the nearly significant difference of the first to the second condition (BASE1-SECT1, as well as BASE1-smTLT) does not support the proposed influence of otolith input but rather a training effect manifesting itself in an increased consistency.

3s Interval

Average Interval Productions and Slopes. As for the 1s interval, Paired samples t-Tests (2-tailed) revealed no significant differences for any of the comparisons of conditions for average interval productions (all *p*>.295) or average slope calculations (all *p*>.329).

Standard Deviations. There were significant differences between **BASE1-BASE2** with *t*(7) = 2.917, *p* < .05, between **BASE2** and the experimental condition **ROLL** (*t*(7) = -3.479, *p* < .05). The comparison BASE2-SECT4 nearly reached significance with *t*(7) = -2.09, *p* = .075. All other comparisons were *p*>.162. BASE1 and the ROLL-condition showed significantly larger standard deviations than BASE2 again suggesting that differences in conditions can be entirely explained with a training effect.

8s Interval

Average Interval Productions and Slopes. Paired Samples t-Tests (2-tailed) of average interval productions revealed no significant differences for any of the comparisons (all *p*>.080). The same comparisons based on individually calculated slopes also lacked significance. However they showed that BASE1-BASE2 nearly reached significance with *t*(7) = -2.30. *p* = .055, all other comparisons were *p*>.283.

Standard Deviations. In contrary to the other two intervals, no significant differences evolved from comparison of conditions for standard deviations, only comparison of BASE1 and BASE2 nearly reached significance with *t*(7) = -1.94, *p* = .094 (all other comparisons were *p*>.238) suggesting stable and consistent productions across conditions.

The following Table 1 gives an overview of the results of all of the intervals tested:

Table 1 EXP ROLL: average interval productions, slopes and standard deviation (SD). Numbers in brackets show percentage of over-estimation of the required interval 1, 3 or 8s.

Time interval	base1	SECT1	SECT2	SECT3	SECT4
1s	1465.8 (47%)	1488.2 (49%)	1510.1 (51%)	1512.5 (51%)	1531.2 (53%)
3s	3837.3 (28%)	3769.1 (26%)	3708.7 (24%)	3681.8 (23%)	3709.2 (24%)
8s	9443.7 (18%)	8566.1 (7%)	8640.0 (8%)	8666.6 (8%)	8527.4 (7%)
SLOPE 1s	0.063	-0.026	0.000	0.001	-0.007
SLOPE 3s	-0.002	-0.007	-0.009	-0.008	-0.010
SLOPE 8s	-0.001	0.000	0.001	0.000	-0.002
SD 1s	126.5	125.7	100.7	102.2	101.0
SD 3s	329.9	280.3	322.4	299.6	277.3
SD 8s	737.4	491.7	575.1	507.3	512.1

Constant roll movement and the resulting otolith signals did not have any systematic effect on interval production but showed that the consistency of produced intervals increased significantly over time; standard deviations were significantly lower for sectors 1 and 2 compared to the first condition base1 for both the 1s and the 3s intervals.

The lacking effect of roll movement on average interval productions and slopes is in line with reports of the participants and own observations that the stimulation could easily be shut out and did therefore not interfere with the task of time production. For further experiments it would be interesting to investigate whether attention explicitly directed towards the roll movement interferes with the time production task as was seen during strong vestibular stimulation.

Experiment POS

Introspective Reports

When asked about participants' perception of the time production tasks in the experimental conditions, two groups of participants emerged: The first and larger group reported the 135° condition to be the least comfortable and explained this with cognitive aspects such as "not exactly knowing where I am" (loss of orientation). The second group reported 180° as the most difficult and least comfortable position and gave somatosensory reasons (blood in head and resulting vertigo).

No significant difference between positions to the right or to the left (7 participants each) was found and so positions to the left were analyzed together with positions on the right (CW90° with CCW-90° and CW135° with CCW-135°).

Effect of Intervals

As in EXP ROLL, intervals were produced too long in all of the conditions, again this was most strongly the case for the 1s interval where the estimated interval was 39% longer than objective time. The over-estimation of the intervals decreased to an average of 13% for the 3s interval and to 9% for the 8s interval (also see Table 2 further down for a more detailed overview).

Effect of Position

Paired Samples t-Tests (2-tailed) were conducted for the following comparisons of conditions: BASE1-BASE2, BASE1 and BASE2 compared to: POS (experimental conditions grouped: 90°, 135° and 180°) and each experimental position separately.

1s Interval

Participants again showed large interindividual differences (see Figure 16 and compare with Figure 15) quite similar to EXP ROLL, suggesting an intra-individual stability of time productions.

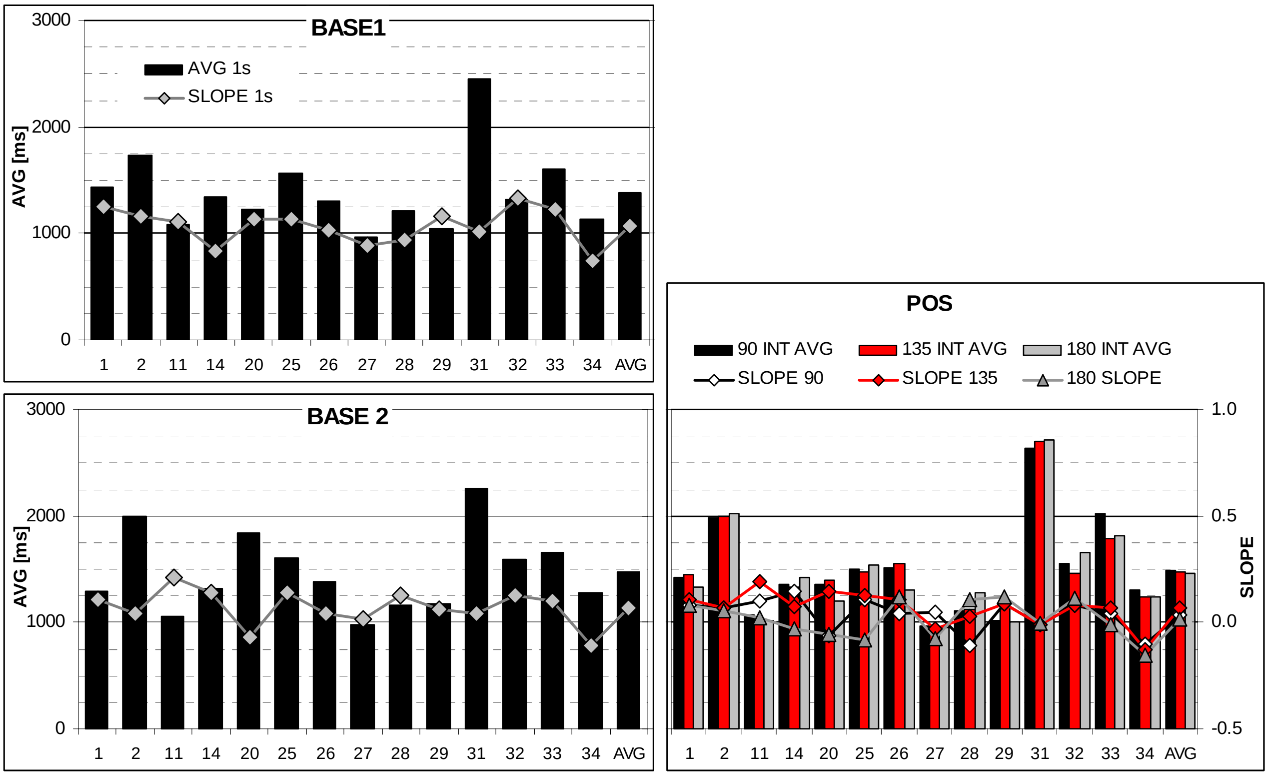

Figure 16 1s-Interval: Individual data given for the baseline conditions (**LEFT**) and the experimental condition (**RIGHT**) for the experimental positions 90, 135 and 180. The left axis refers to the average interval production and the right to the average slope calculation. (N=14)

Average interval productions. Paired Samples t-Tests (2-tailed) of average interval productions revealed significant differences for the comparisons **BASE1-POS** ($t(13) = -2.58$, $p < .05$), for **BASE1-90** ($t(13) = -2.43$, $p < .05$), for **BASE1-135** ($t(13) = -2.38$, $p < .05$ and BASE1-180 almost reached significance with $t(13) = -2.05$, $p = .061$. All other comparisons were $p > .157$. Average time interval productions in BASE1 were always lower than the significantly different conditions.

Slopes. The same comparisons based on individually calculated slopes showed significant difference between **BASE2-180°** with $t(13) = 2.30$, $p < .05$. All other comparisons were $p > .110$.

Standard Deviations. As in EXP ROLL, standard deviations showed several highly significant effects for the following comparisons: **BASE1-BASE2** ($t(13) = 6.26$, $p < .001$), **BASE1-POS** ($t(13) = 8.04$, $p < .001$), **BASE1-90** ($t(13) = 6.71$, $p < .001$), **BASE1-135** ($t(13) = 8.47$, $p < .001$), **BASE1-180** ($t(13) = 8.24$, $p < .001$). In all of these cases BASE1 always showed a higher standard deviation which, as mentioned before, speaks for a general gain of consistency. All other comparisons were $p > .164$.

3s Interval

Average interval Productions and Slopes. In contrary to the 1s interval, Paired Samples t-Tests (2-tailed) of neither average interval productions (all p>.272) nor calculated slopes revealed significant differences between the conditions. The analysis of slopes however showed that the comparison of BASE2-90 nearly reached significance with $t(13) = -2.07$, $p = .059$. All other comparisons were p>.142.

Standard Deviations. Standard deviations showed only minor significant effects for the following comparisons: **BASE1-BASE2** ($t(13) = 2.33$, $p < .05$) and **BASE2-180** ($t(13) = -2.37$, $p <$ .05. Also, comparison BASE2-135 almost reached significance with $t(13) = -2.14$, $p = .052$. All other comparisons were p>.111. Again, decreased standard deviation in the course of time suggests training effects leading to higher consistency of produced time intervals.

8s Interval

Average interval Productions and Slopes. As with the 3s interval, there were no significant differences of condition showing, neither in average interval productions (all p>.091), nor in individually calculated slopes (all p>. 290).

Standard Deviations. Comparable with the 3s interval there was again a minor significant difference between the conditions **BASE1-BASE2** with $t(13) = 2.52$, $p < .05$ and **BASE1-180** ($t(13) = 2.38$, $p < .05$). The comparisons BASE1-POS only nearly reached significance with $t(13) = 2.01$, $p = .066$. All other comparisons were p>.137.

The following Table 2 and Figure 17 give an overview of the results of all of the intervals tested:

Table 2 EXP POS; average interval productions and standard deviation (SD) Numbers in brackets show percentage of over-estimation of the required interval 1, 3 or 8s.

Time Interval	base1	90	135	180	base2
1s	1387.7 (39%)	1485.0 (48%)	1474.4 (47%)	1465.0 (47%)	1469.1 (47%)
3s	3375.9 (13%)	3382.7 (13%)	3420.6 (14%)	3246.1 (8%)	3317.4 (11%)
8s	8699.4 (9%)	8690.2 (9%)	8915.3 (11%)	8416.9 (5%)	8466.1 (6%)
SLOPE 1s	0.034	0.037	0.066	0.014	0.069
SLOPE 3s	0.012	0.000	0.000	0.000	-0.10
SLOPE 8s	0.000	0.000	-0.001	0.002	0.000
SD 1s	199.8	90.9	98.1	81.7	90.3
SD 3s	233.4	174.6	178.7	175.9	139.1
SD 8s	495.9	390.9	465.1	384.2	321.6

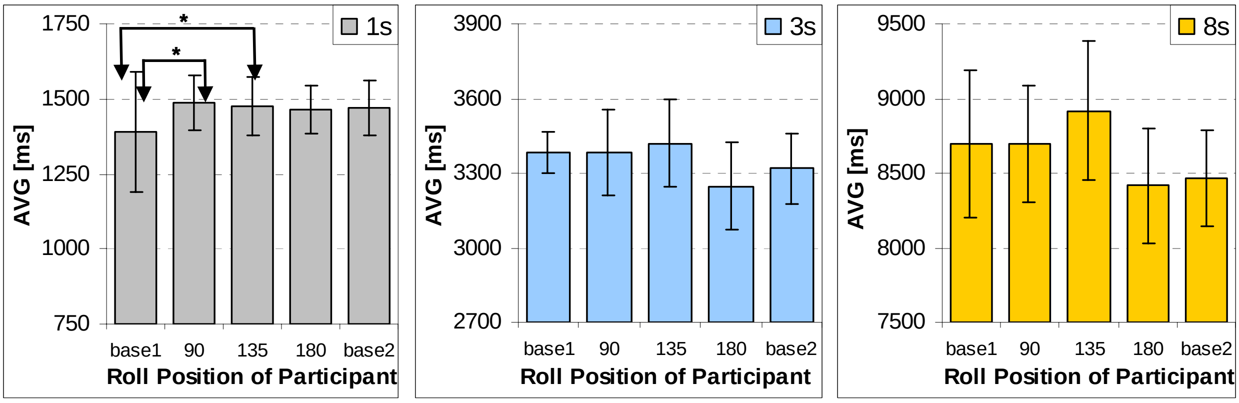

Figure 17 Overview of average interval productions and interindividual standard deviation (error bars) for the 1s, 3s and 8s interval

Only for the production of the short interval, there was a significant difference of average interval productions during the first baseline condition and during the positions 90° and 135°. The increased durations of produced intervals again suggest that the concurrent non-temporal vestibular information increased cognitive load. As was seen in EXP ACC-DEC this however only shows for the short interval of 1s. This suggests that otolith stimulation could have yielded a similar interaction with cerebellar processing; the additional input lead to longer interval productions.

The highly significant decrease of standard deviation further emphasizes the training effect noticed within the first conditions of EXP ROLL. Since positions were balanced throughout the participants, this training is highly significant for all comparisons of positions with baseline 1.

Comparison of EXP ROLL and EXP POS

Separate consideration of EXP ROLL showed no systematic effects of constant roll movement. In EXP POS on the other hand static roll positions equal or larger 90° lead to a systematic increase of produced interval durations for the 1s interval. The difference noted between 1s and the longer intervals 3s and 8s could imply the use of different strategies applied for "short" and "long" intervals as has been discussed previously. Different results for the three intervals may be due to different strategies for different intervals: In line with subjective reports, the 1s interval was produced in a rather motor-controlled way, while participants were more strongly busy with mentally "counting along" in the longer two intervals (also see IVRY & HAZELTINE, 2004A). It seems noteworthy that the "more cognitive" timing of long range timing did not seem to increase produced intervals, quite contrary, the "more automatic" timing was influenced when remaining in unusual and confusing body positions.

Participants were quite consistent with "their" concept of the intervals, which shows in high correlations between the first baseline (EXP ROLL) and second baseline (EXP POS) with average correlation values of r=.95 for the 1s interval, r=.80 for the 3s interval and finally r=.65 for the 8s interval. Strategies applied and reported differed especially between the 1s and other intervals. Either a kind of clock pulse was applied for the 1s interval or participants repeatedly were counting (21, 21, 21 or one, two, three, four,..., also see GUAY & WILBERG, 1983) for the other two time intervals. All of the participants counted either quietly or loud. Most participants reported applying the same strategies in both experiments no matter how many days apart these took place. This fact corresponds with decreased standard deviation in the course of the experiments and clearly suggests a training effect with participants improving their consistency of productions (see Figure 18). This visible trend of decreased standard deviation however, was not significant when comparing the two consequent experiments EXP ROLL and EXP POS; only for the 1s interval the effect almost reached significance with p = .056. It is possible that EXP ROLL might have evoked higher standard deviations because here weak stimulation of semicircular canals could have been present. Yet, the interpretation of a training effect seems more plausible since consistency improves even within the first conditions within the two experiments.

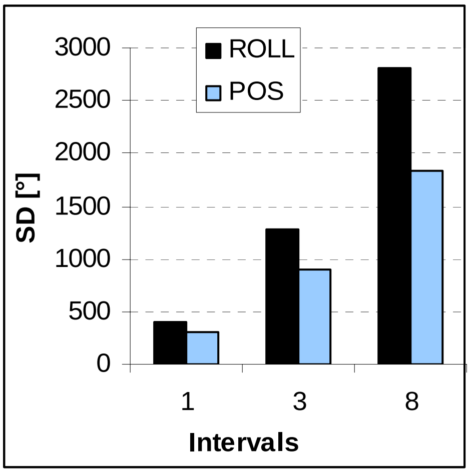

Figure 18 Standard Deviation (SD) shown for all of the intervals (grouped together) tested for the baseline1 condition: they decrease from the first (EXP ROLL) to the second experiment (EXP POS) (N=14, n=70 per participant).

Especially for the ROLL condition participants gave various individual impressions of the same machine movement. This indicates the ambiguity of the vestibular signals and also shows an adaptation to a given situation where in the course of time perception of movement was increasingly closer to the objective movement. Yet, subjectively perceived difficulties in space perception obviously are not reflected in the interval productions. This may be due to the fact that space perception happened without "conscious" time perception and is hence more automatically processed. Introspective reports showed that the "mental counting" on the other hand was very well conscious. The effects of altered time productions – as found for slopes in EXP ACC-DEC – could not be replicated in the setting of minor rotation velocity. In EXP POS, slope calculations of the 1s interval only differed between BASE2 and roll position 180°. The data indicate that produced intervals in the 180° position got slightly but increasingly shorter. This might be explained with the fact that prolonged lingering in the 180° position can be stressful and explain this finding. In general, one can assume that the results found in EXP ACC-DEC were most probably due to the involvement of the semicircular canals.

The large individual differences found in both experiments speak for differences in individual production strategies, but could also reflect individual differences in cognitive conceptions of the time intervals. Another possible explanation would be that people indeed differ in the way they perceive time and have different "time thresholds" (snails vs. tigers). It also needs to be considered that enhanced attention to time itself may cause altered time perception/production and this effect could have acted differently upon different participants.

By not explicitly instructing participants to focus on movement during the time production task, movement might have easily been shut out as a task-irrelevant factor easy to be ignored. Further experiments could more reliably draw participants' attention either by comparing active with passive movement or by instructing them to focus on movement. Future research could test participants with a more complex time production task such as to continuously tap rhythmically or sing instead of doing the monotonous task they did (also see MCAULEY & JONES, 2003).

1.3. General Discussion

Disturbance of time processing

Results by ISRAËL ET AL. (2004) suggest that subjects mentally count during self-transport and therefore use time to estimate distance. The authors find that counting is disturbed by passive self-motion with varying velocity, suggesting that participants could not count with regularity and were not able to appropriately weight time increments according to the current level of acceleration. This could be confirmed with EXP ACC-DEC by yielding negative slopes of time productions in the acceleration condition and positive slopes during deceleration.

Based on the fact that vestibular information and time-relative processing both feed on the cerebellum it was supposed that the type of vestibular stimulation in EXP ACC-DEC leads to specific influence on time productions. Average intervals did tend to increase – mostly so in the acceleration condition – in experimental conditions that were more demanding cognitively. Furthermore, in the course of time, productions did in fact progressively become shorter in the acceleration condition and progressively longer in the deceleration condition for the 1s interval. Productions were also comparatively longer during imagery, sometimes compared to the baseline condition (DEC, 8s; ACC 15s) and sometimes even compared to the perc1 condition (DEC, 15s). This could imply that the longer the interval to be produced, the stronger the effect of slowing down during increased mental load.

The constant otolith stimulation in EXP ROLL was not able to yield systematic effects of experimental conditions, but in EXP POS time productions did increase in the positions 90° and 135°. These were also the positions most often reported to be confusing.

Attentional Resources and Adaptation

According to ZAKAY AND BLOCK (2004), temporal and non-temporal information share common attention resources. Like a computer, the mind has a limited capacity (shared resources), and tasks will slow down if there are too many running at once (cognitive load). A mental slow-down can result from the mind trying to do too much at once as it is the case in dual-task situations.

Considering the confusion reported by participants for positions equal or larger than 90°, this could explain the augmented intervals found in prolonged lingering in these unusual positions. FRAISSE, 1984 finds that the intensity of the interval is relevant; the more intense the stimuli, the longer they are judged compared to less intense stimuli. One could consider the 1s interval to be more "intense" due to the higher frequency of interval tapping compared to the longer intervals tested. This could also explain why the 1s interval was produced 39-46% too long while this effect is diminished for the longer intervals (28-13% for the 3s interval and 18-9% for the 8s interval). The same authors claim that the nature of processing required of the subject while estimating short intervals is also important: it has been shown that intervals are reproduced longer when they are filled than when they are empty (FRAISSE, 1984). The unusual acceleration and deceleration, as well as the unusual and confusing positions tested in EXP POS could be regarded as external events "filling" the intervals while the constant movement in EXP ROLL was "successfully" ignored.

All of the intervals were produced too long. The effects of vestibular stimulation found in the present study were always limited to the 1s intervals. It is suggested that this more "automatic" processing (LEWIS & MIALL, 2003) – reflecting the engagement of processes associated with the production of skilled movements – is more strongly biased than the more "cognitive" timing. The latter depending on neural systems associated with attention and working memory (IVRY & SPENCER, 2004A). It is conceivable that for the longer intervals (3s, 8s, 15s), attention was less distracted and more strongly directed to time production. The predictions made for time productions during high cognitive load (ZAKAY & BLOCK, 2004) apply to the production of short intervals. Conducting other activities during prospective time estimation – therefore attention being shared – leads to fewer time signals being accumulated and to an over-estimation of time (intervals produced too long) and to a higher variation (as shown by BROWN, 1997). In EXP ROLL and POS the increased variation could not be confirmed, on the contrary, decreased standard deviations in the course of the experiments suggest a pronounced training effect with participants being increasingly consistent with their concept of the required interval.

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2. Influence of Cognition on Perception (Top-Down)

2.1. Introduction

"Perceptions and thinking are only there for
behavior's sake."
W. JAMES (1881)

The integration of sensory information is one of the most important prerequisite to adapt behavioral control on to situations faced in our surroundings in an optimal way. Sensory information is coded in different reference systems and needs to be integrated into a consistent space concept. The merging of relevant sensory information is relevant for multisensory integration and the integrative function of CNS is the basis for a stable orientation in space. The term "space concept" therefore implies the convergence of visual, vestibular, auditory and somatosensory inputs. Interestingly, all brain areas associated with vestibular functions are multisensory areas (BRANDT ET AL., 1998).

State of the Art Research on Visual-Vestibular Interactions and Illusions

Vestibular stimulation invariably leads to the sensation of body motion. Viewing visual motion however always allows two perceptual interpretations: either self-motion or object-motion (BRANDT ET AL., 1973). A well known experiment showing the visual influence on the perception of body tilt was conducted by DICHGANS ET AL. (1972, also see BISCHOF & SCHEERER, 1970). In their experiment, participants are presented a black and white stripe pattern rotating about their mid-body-axis (large-field motion stimulation). This kind of visual rotation leads to the sensation of self-motion, termed circular vection (CV) (DICHGANS ET AL. 1972). BRANDT AND DICHGANS (1972) find that this circular motion of an entire surrounding (rotating drum) invariably leads to an apparent self-rotation which is indistinguishable from an actual chair rotation; the visually induced pseudo-coriolis effects are subjectively identical to vestibular coriolis effects. Apparent self-motion is a common visual phenomenon, from which inferences on visual-vestibular interaction can be drawn (DICHGANS & BRANDT, 1978). This CV is not an insignificant illusion, but an essential mechanism for adequate perception of self-motion in order to control postural balance. BRANDT, DICHGANS AND KÖNIG (1973) investigated occlusion of either the periphery or the central visual field. In the central occlusion the given effect of CV was still fully present, while in the peripheral occlusion, when only 30° diameter of the central field was visible, exclusive egocentric motion perception of the surrounding was experienced. When simultaneously presenting conflicting central and peripheral optokinetic stimuli (i.e., stimuli rotating in opposite directions) exocentric orientation depended on the peripheral stimulus whereas optokinetic nystagmus and the perception of egocentric motion rely on the centre of the visual field. In a study by MAST AND BERTHOZ (2001) an illusory shift of the direction of gravity lead to an apparent tilt of the body and displaced allocentric space coordinates when measuring the adjusted indicator to the apparent horizontal (SVH). The results demonstrate that top-down processing affects allocentric space coordinates. Studies in weightlessness have shown even stronger effects of roll-vection stimulation than do occur when gravity is present (YOUNG ET AL., 1986A; YOUNG, SHELHAMER & MODESTINO, 1986B).

Visual Motion Illusions

PURKINJE stated "illusions of the senses tell us the truth about perception" or as GREGORY (2005) put it "... illusions as keys for unlocking secrets of perception". Illusions therefore offer an alternative and elegant way to explore the function of the senses/perception and the limits thereof. There are many visual illusions that appear to be moving; here I will concentrate on the illusion applied in the following experiment. When not focusing directly on the circle in Figure 19 but looking at it in the periphery, it appears to be moving towards the right. KITAOKA AND ASHIDA (2003) propose this "corrected pattern" of the Fraser-Wilcox Illusion (FRASER & WILCOX, 1979[8]) which gives a stronger illusion by adding stepwise profiles (fragments with slightly rounded edges) and considering the critical order of regions with different luminance (combination of black and dark-gray or combination of white and light-gray). The background also attributes to a more intense motion perception in a specific direction. The authors further use this "optimized" FRASER-WILCOX illusion (see Figure 19) in designing the illusion they called 'rotating snakes'[9].

KITAOKA (2006) investigated what factors – such as color and saturation – are able to increase the perceived motion and found that blue-yellow versus red-green combinations are most effective. He did not find evidence that saturation of the colors has an effect, however, the magnitude of the illusion decreased when the luminance of two colors approached each other. This suggests that color alone might have little effect on this illusion. In a physiological experiment, CONWAY ET AL. (2005) also report that luminance is a critical feature to induce the illusory motion. The same authors for the first time demonstrated directional responses by single neurons of macaque visual cortex to static displays and support a model in which low-level, first-order motion detectors interpret contrast-dependent differences in response timing as motion.

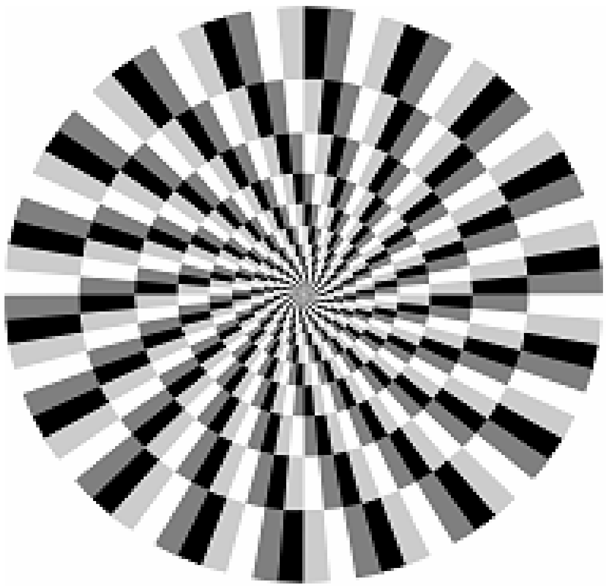

Figure 19 The optimized FRASER-WILCOX illusion. This disk appears to rotate clockwise.

FAUBERT AND HERBERT (1999) list a number of conditions that have to be met to perceive the illusion: First, there has to be a *resetting process* whereby transients are generated in the visual system (as a result of eye movements, blinks, movement of the display etc.). Second, the *lumi-*

[8] FRASER AND WILCOX (1979) investigated the motion illusion named „Escalator Illusion" and find that out of 678 participants 25% do not experience any motion at all, 59% experience motion from light to dark (rightward rotation) and 6.5% from dark to light (leftward rotation). The remaining 9.5% participants experience motion in both directions. The authors suggest genetic differences for this phenomenon.

[9] See homepage of AKIYOSHI KITAOKA at http://www.ritsumei.ac.jp/~akitaoka/index-e.html

nance gradient determines the direction of perceived motion (luminance information travels through the visual system at different latencies: lighter information passes through the system faster than dark information. Third, the illusion is only perceived with *eccentric viewing* because information is integrated over comparatively large regions in the periphery. These three processes generate the illusory motion (*peripheral-spatiotemporal-integration hypothesis*). NAOR-RAZ AND SEKULER (2000) further investigated the conditions that have to be met to perceive a pronounced motion and found that the longer the duration of illusion presentation and the larger the distance between stimulus and point of focus (eccentricity), the stronger the motion illusion. These authors also found an increase of motion perception with better contrast between the different bars[10]. ZEKI, WATSON & FRACKOWIAK (1993) suggest that higher-level processes are responsible for the perception of illusory motion. In their view, a static stimulus induces activity in a given region of the visual cortex which then invests the stimulus with a particular perceptual quality, the latter being entirely the construct of the brain. In a diametrically opposed viewpoint, GREGORY (1993, 1995) argues for low-level processes as the cause of the illusion. He proposes that the dynamic shimmer seen in the static figures has an optical cause: changes of size of the retinal image due to the usual rapid "hunting" of accommodation. Based on the Enigma illusion – a static figure painted by the artist LEVIANT – FERMÜLLER, PLESS AND ALOIMONOS (1997) offer a computational approach that combines the two opposing theories. According to them the mechanisms behind the higher-level processes are triggered by low-level retinal motion signals.

Interestingly, there are some observers who do not see this illusion at all. KITAOKA (2005) reported 5%, while Fraser AND Wilcox (1979) found 25% belonging to this group.

The question raised is if – in line with the apparent motion illusions mentioned above – this kind of motion illusion (perception of visual motion which is in fact motionless) can lead to a false interpretation of body tilt and alter adjustments of the subjectively perceived horizontal body position.

Experiment

The following experiment deals with the influence of visual information (presentation of a visual motion illusion) on apparent body tilt. People are quite precise when asked to adjust themselves to a fully horizontal position in complete darkness (JARCHOW, 2002). It is suggested that the visual motion information provided by a peripheral drift illusion ('rotating snakes') increases cognitive load mediated through the processing of motion and in turn decreases the consistency of subjective horizontal (SH) adjustments.

[10] Also see DERRINGTON ET AL. (2004) for a review on visual mechanisms of motion analysis and motion perception.

2.2. Influence of Illusory Visual Motion on Perceived Body Position

Abstract

Can the presentation of a peripheral drift illusion influence adjustments of perceived horizontal body position? While the illusion does not lead to a general shift of average SH adjustments, the standard deviation is indeed augmented compared to a condition conducted in complete darkness. However, the effect shows more strongly for participants starting off with the condition in complete darkness as opposed to those starting with the condition with presentation of the visual motion illusion. These participants (6 persons) also show a marginally significant shift of average SH.

Introduction

"Manipulation" of cognitive or perceptive information offers an interesting way to test the limits and capacities of these processes. Can perception fool cognition (such as in illusions) or can cognition fool perception (such as in interpreted movement)? Previous studies have dealt with visual-vestibular tasks where "cognitive" interpretation of the visual display leads to systematic changes in the way they perceived their position. Experiments with visual movement information have been able to show an effect on how participants perceive, respectively adjust specific body positions (DICHGANS ET AL., 1972). LOOSE AND PROBST (2001) find that perception of visual motion is impaired by concurrent vestibular stimulation (also see PROBST ET AL., 1984). These vestibular-visual interactions were found to occur for both rotational self-motion (BRANDT, 1982; BRANDT, DIETERICH & PROBST, 1990; BÜCHELE, DEGNER & BRANDT, 1980; BUIZZA ET AL., 1980; MERGNER ET AL 1992; PROBST AND WIST 1990) and translational (linear) self-motion (DICHGANS & BRANDT, 1978; PAVARD & BERTHOZ, 1977; PROBST ET AL., 1984; PROBST, KRAFCYK & BRANDT, 1987). With increasing angular acceleration the intensity of vestibular-visual interaction increases (LOOSE, PROBST & WIST, 1996; PROBST ET AL., 1995). This vestibular-visual interaction depends on the angular velocity and is mediated by cortical structures, such as the Medial superior temporal area (MST) and the medial temporal area (MT). The authors find that it is the perception of self-motion – real or apparent – which is responsible for higher detection thresholds.

THILO AND GRESTY (2002) report that visual signals relative to graviceptors might receive an increased weighting and exert a greater influence on the judgment of verticality. The authors find a distinct dissociation between the perception of self-motion (rotation) and the biased perception of verticality (perceived direction of gravity). During optokinetic stimulation in roll subjects' perceived direction of verticality was biased towards the direction of visual stimulus rotation but this was the case irrespective of whether subjects perceived the visual stimulus as originating from object-motion or from self-motion. They suggest that segregated neural substructures mediate the perception of tilt and that of self-motion.

BISCHOF AND SCHEERER (1970) investigated optic-vestibular interactions in the perception of verticality and found that participants show a systematical deviation of subjective visual vertical adjustments of a luminous rod when a field of stripes is slowly rotating in the frontoparallel plane around the subjects' visual axis (off-vertical visual background information). A more recent study applying the visual vertical paradigm and investigating visual-vestibular interaction was conducted by MAST, BERTHOZ AND KOSSLYN (2001). An illusory shift of the direction of gravity triggered by a rotating display leads to an apparent tilt of the body and displaces allocentric space coordinates. Interestingly the mere visualization and actual viewing of a rotating configuration of dots shifts the spatial judgment in a comparable way. These results demonstrate that top-down processing affects allocentric space coordinates and that cognitive processes therefore are quite relevant during a task in space perception.

In a study by SOTO-FARACO ET AL. (2004) on visual-proprioceptive interactions, uncertainty of locus of stimulation leads to larger congruency effects; the more uncertainty of where a vibrotactile stimulus would be applied, the larger the interference is.

Experiments on circular vection (e.g. BRANDT, DICHGANS & KÖNIG, 1973) suggest that the resulting illusion is an essential mechanism for adequate perception of self-motion in order to control postural balance. When the periphery is occluded, this leads to egocentric motion perception. The illusion as presented here therefore is suggested to alter egocentric motion experienced during the adjustment of the SH.

KITAOKA AND ASHIDA (2003) propose a "corrected pattern" of the peripheral drift illusion (FRASER & WILCOX, 1979) which gives a stronger illusion by adding stepwise profiles and considering the critical order of regions with different luminance (combination of black and dark-gray or combination of white and light-gray). The authors use this "optimized" Fraser-Wilcox illusion (see Figure 19) in designing the illusion they called 'rotating snakes'[11] which is applied here.

The aim of the study is to investigate to what extent a visual motion illusion – not directly relevant to the task – leads to altered body perception as reported with real visual motion. Two questions are asked: First, how well can participants adjust the required perceived horizontal body position in complete darkness and second, does the presence of a visual motion illusion lead to an altered adjustment? We hypothesize, that resulting insecurity about one's own position will lead to larger variation of adjustments (standard deviation). Since the motion illusion does not have a specific direction no systematic effect of average adjustments is expected.

Experiment ILLMOVE

Method

Participants

Twelve graduate students (two female, mean age 27.8 years, range 23-35 years) attend the experiment. All participants are naïve with regard to the hypothesis under investigation.

[11] See Homepage of Akiyoshi Kitaoka at http://www.ritsumei.ac.jp/~akitaoka/index-e.html

Materials and Procedure

Apparatus. A tiltboard serves to position the participants outstretched on their right side (see

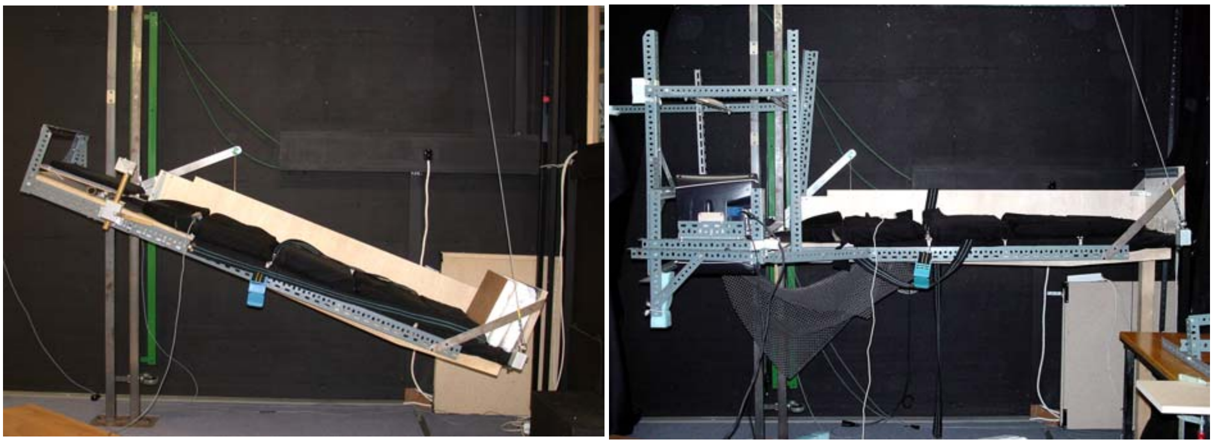

Figure 21 Tiltboard used for the adjustments of the subjectively perceived horizontal (SH).

Figure 21). It is padded to ensure a comfortable positioning during the experiment. There is an opening on the height of the right shoulder where the right arm is fit in and is supported by a net. The tiltboard is moved around a rotation axis at the height of the participants' head. An angular transmitter encodes the tilt adjusted by the participant and is then digitalized with a resolution of 0.04° and recorded by a computer. Tilt is controlled by the participant by pressing buttons on a button box (one for "feet up", one for "feet down", and one to confirm that they reached a horizontal position). All button presses (and according tilt positions) are recorded by the computer. Dark curtains are mounted all around the tiltboard to ensure absolute darkness and to eliminate visual cues that could be used for orientation during the experiment.

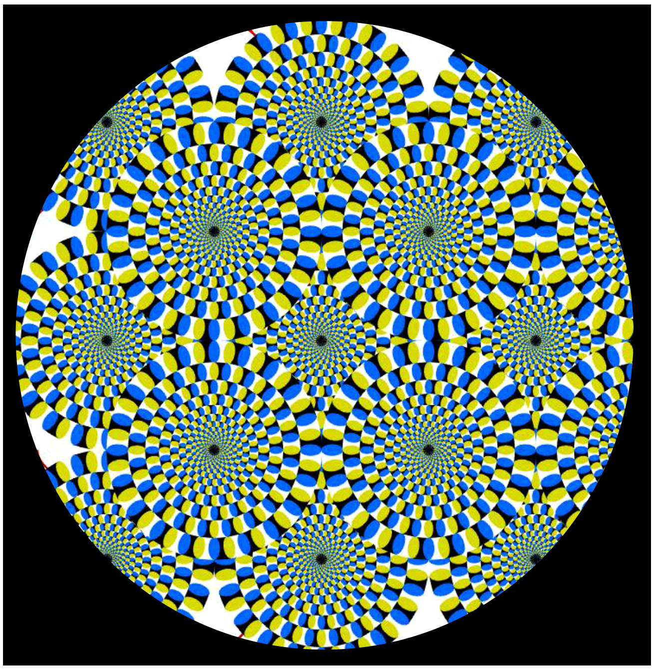

Figure 20 'Rotating snakes'; motion illusion as presented to the participants

Stimuli. A monitor is mounted in front of the participants' heads and the illusory motion picture is presented on a flat screen monitor (PC Intel Pentium III processor, 750 MHz, 256 MB RAM with a resolution of 1024 X 768 pixels) (see Figure 20). A cardboard tube is attached to the screen leaving the participants viewing only a circular view of the screen. Eye to monitor distance is 36cm and the diameter of visible section of 'rotating snakes' illusion (KITAOKA, 2003) is 21 cm (visual angle ≈ 33°[12]). Viewing the illusion results in the perception of a con-

[12] This is comparable to what BRANDT, DICHGANS AND KÖNIG (1973) refer to as central viewing which is known to cause egocentric motion perception.

stant illusory motion experienced in both clockwise and counterclockwise direction simultaneously. The constant motion is enhanced and refreshed with continuous eye movements (see BRANDT ET AL., 1990; FAUBERT & HERBERT, 1999).

Experimental procedure. Participants are positioned on the tiltboard with a starting position of 55° (position shown on the left side of Figure 21). After the light has been turned off and the participants signaled that they are ready, they are asked to adjust their body position to the subjectively perceived horizontal repeatedly (SH, ROLL90°, the position they would adopt when lying sideways on a bed (exact Instruction see Appendix 1). They move the tiltboard up and down by pressing the according button on a button box and press a button when they believe to have reached the horizontal position. The method of limits is applied; after every adjustment, the tiltboard is automatically moved away alternating +/- 15°.

Two conditions are conducted and counterbalanced within the participants. Condition NO takes place in complete darkness, while in the condition ILL participants see part of the illusory motion through a circular opening to the screen. After 14 adjustments of the SH the tiltboard is moved back to 55°. Every condition lasts approximately 20min leading to a total of about 45min for the entire experiment.

To ensure continuous apparent motion illusion the participants were asked to answer questions on the illusion display during SH adjustments of condition ILL (Questions see Appendix 2).

Results and Discussion

Data exclusion criteria:

- The first adjustment is not included in data analysis to allow participants to accustom to the task.
- False button presses were excluded (1.3% of all adjustments).

Subjective Reports

All participants reported that they experienced a visual motion illusion on the presented screen.

Analysis of Average SH Adjustments

A first glance at all of the adjustments of all of the participants (see Figure 22) reveals that adjustments of the subjectively perceived horizontal are higher (feet up) in the condition with the motion illusion (ILL) relative to the condition without any visual input (NO). A statistical analysis of the data also revealed the known hysteresis effect between the adjustments following automatic positive and negative pre-positions (also see Figure 24). This effect is due to the method applied (described

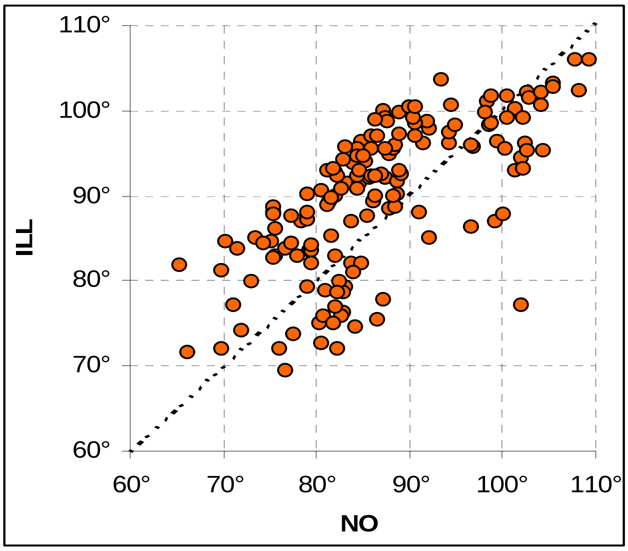

Figure 22 Adjustments during the illusion condition (ILL) are more often higher (feet up) compared to those in the NO condition without any visual input. Dots on the diagonal would represent equivalent adjustments in the two conditions (n=156).

by JARCHOW, 2002); on average participants only move back 88% from the preceding automatically generated position. This is the same result as JARCHOW gets for an automatic deviation of 12° versus the +/- 15° applied here (2002, P.38). Adjustments are always biased towards the preceding automatically generated position.

Average adjustments in the two conditions show that the SH deviates 5.3° (NO) or 2.5° (ILL) from the horizontal which means that the head relative to the feet is positioned too high. Only the condition NO marginally yet significantly deviates from the required 90° position, with $t(11) = -2.26$, $p < .05$.

A Paired Samples t-Test (2-tailed) reveals that there is no significant difference of average SH adjustments between condition NO (AVG= 84.7, SD=9.1) and ILL (AVG=87.5, SD=10.5) with $t(11) = -1.72$, $p = .114$. Interestingly, analysis of standard deviation (SD) does reveal a significant difference between the conditions with a higher level of SD for the condition with the illusory motion $t(11) = -2.28$), $p < .05$ (see right side of Figure 23).

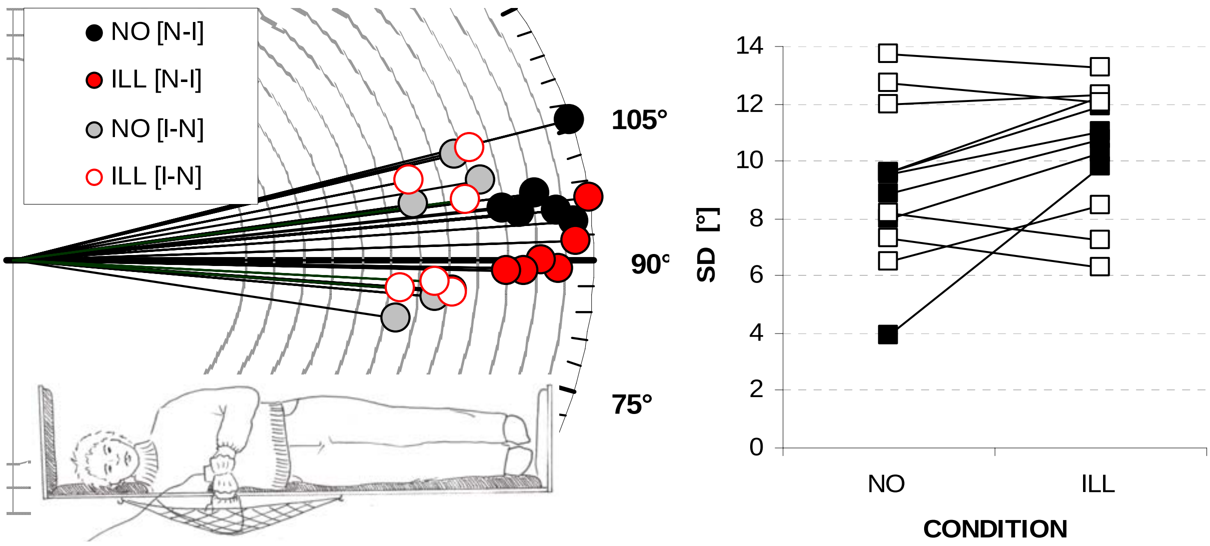

Figure 23 LEFT: Average SH adjustments do not significantly differ (black and light grey circles: condition NO; dark and open circles: condition ILL; N-I stands for participants starting with the condition NO, I-N stands for participants starting with condition ILL, while **RIGHT:** SD shows significantly higher in the condition with the illusory motion (filled squares: ORDER NO-ILL, empty squares: ORDER ILL-NO)

There is a significant effect of ORDER of CONDITIONS for average SH adjustments $t(11) = -3.36$, $p < .01$ with average adjustments approaching the required 90° body tilt position and also for SD ($t(11) = -2.60$, $p < .05$) with standard deviation significantly increasing in the second condition. The slightly yet significantly ($p < .05$) increased SD in the second session is explained merely with the group that started with NO and then showed a significant increase in the ILL condition. Figure 25 shows groups of participants separately; according to if they started with ILL as their first or second condition. This result leads to the assumption that there is an increased effect of the illusion when the first condition is conducted in darkness. The increased inconsistency is reflected in the disproportional and significant increase of SD, suggesting that the system is more impaired

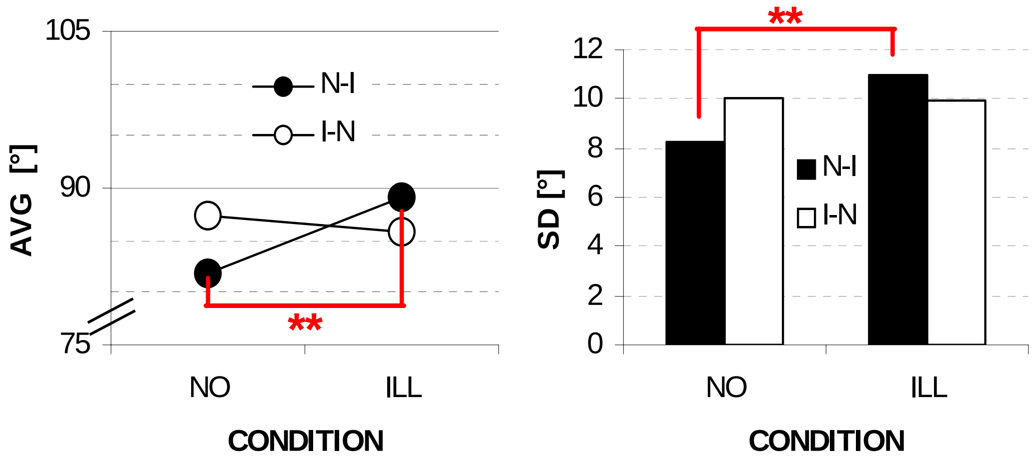

Figure 25 LEFT: AVG SH and **RIGHT:** SD data split into the groups in relation to ORDER of CONDITIONS

when the adjustments in the first condition (NO) are "disturbed" by the illusion[13] in the second condition. JARCHOW (2002) found that when presenting rotating black and white stripes in a sphere in front of a horizontally positioned subject, adjustments of the subjective horizontal are shifted 2° in the head-down direction. The present results show a similar effect for participants starting with the NO condition. JARCHOW (2002, P. 36) criticized the balancing of conditions with these kinds of vestibular experiments because "any manipulation will have an impact on subsequent experiments". It is very well possible that any kind of additional information can be regarded as noise distorting the data received from vestibular sensors. This leads to a larger variability of adjustments and to systematically different average adjustment of the subjective horizontal for the group starting with the "unimpaired" condition NO. Further interpretation however would require an assessment of a larger number of participants.

A post-hoc analysis of average order of adjustments (across participants) shows that participants seem to need quite some time to adapt and "find their SH" (see Figure 24). There obviously is a general trend to increasingly approach the required 90°. One could argue that adjustments keep on increasing with the head being adjusted lower than the feet, but a flattening of the curve implicates that the adjustments more or less end up reaching a plateau. The analysis of individual data showed that while only four participants showed a strong increase of adjustments throughout the experiments, the majority reached a plateau after only one or two adjustments and stayed there. Nevertheless, the difference of average

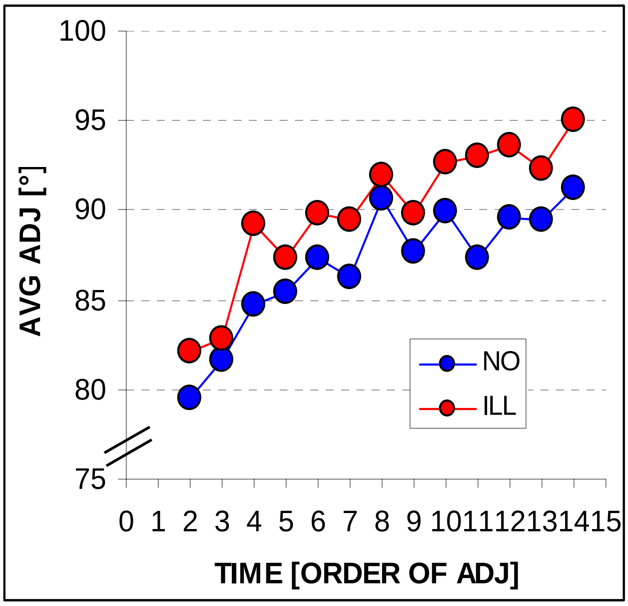

Figure 24 Adjustments shown in the course of time; the hysteresis effect is visible in the apparent zigzag course of adjustments (e.g. the first adjustment shown was preceded by a positive pre-position.

[13] This interpretation needs to be interpreted with care since the amount of participants per group is only 6.

of the first five adjustments (2-7) compared to the last five adjustments (9-14) was highly significant ($p < .001$) and the question arises whether more than only the first adjustment should be excluded for data analysis, allowing the participants to get more familiar with the task.

The presentation of the motion illusion did not lead to a systematic displacement of adjustments (when the factor ORDER is neglected) but to a larger standard deviation which seems due to more uncertainty in knowing "where I am" and in adjusting the subjective horizontal during the experimental condition with the motion illusion present.

There are circumstances in which other sensory systems impact the sensory thresholds of the vestibular system. For example, HUANG AND YOUNG (1981) found that while the level of illumination produces no significant differences in the threshold for perception of angular velocity, the absence of illumination significantly lowers the threshold and reduces latency time. It can therefore not be ruled out, that the presence of light or any kind of visual information – no matter how relevant to the task – leads to a larger variation of adjustments.

Further research is necessary to investigate if light (without supplying spatial information) or task-irrelevant visual information by itself is able to increase variation of adjustments. Furthermore, it would be interesting to apply an illusory motion in one discrete direction (e.g. the barber pole-illusion, FISHER & ZANKER, 2001; or a single moving circle produced based on the principles of KITAOKA, 2006) and compare this to a physically identical situation (real motion) and to a baseline condition without any visual information provided. Some participants report that they feel more certain adjusting when they have their eyes closed, even though the experimental room is absolutely dark. Possibly the fact that the eyes are open is relevant and can lead to less precise/consistent adjustments. With closed eyes, attention is entirely focused on vestibular information to adjust the SH. A further experiment to clarify this issue could test subjective horizontal body position with three different "visual" conditions: eyes open (in darkness), eyes closed (in darkness) and eyes open (with light yet not providing any information on space directions). Also, individual differences concerning the susceptibility to visual information could be closer examined.

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II. COGNITIVE AND PERCEPTUAL FACTORS IN MENTAL ROTATION

1. Introduction

General Remarks on Mental Imagery

Cognitive psychology emerged from the "cognitive revolution", an intellectual movement in the 1950ies. One of the main ideas was that by studying and developing successful functions in artificial intelligence and computer science, it would become possible to create testable inferences about human mental processes. Cognitive psychology furthermore deals with how we manipulate (transform) representations (GAZZANIGA, IVRY & MANGUN, 2002); the cognitive process of imagery is the term used to refer to the creation of any experience in the mind, it can be auditory, visual, tactile, olfactory, or gustatory. The success of the cognitive scientists in predicting and describing human behavior prevailed over the strict behaviorist approach and by the early 1990ies the cognitive approach had become the dominant research line in many of the (applied) psychology research fields.

The concept of imagery describes intentionally imagined pictures and processes which can be consciously controlled and are related to physical reality. When thinking about a previous or upcoming event, people commonly use imagery. For example, one may ask, "What color is your couch?" The answer to this question is commonly retrieved by using imagery (i.e., by a person mentally "seeing" his or her couch). Imagery would be of limited value if we could only recall past events or recombine these memories in specific ways. In many cases we want to "turn something over" in our minds (SHEPARD & COOPER, 1986). One of the most interesting facts about image transformations is that they often preserve the time course of the corresponding actual transformation. Imagined experiences thus seem to imitate sensory or perceptual experiences. According to KOSSLYN (1994) a visual image is "seeing" in the absence of a corresponding immediate sensory input. In spite of the fact that images are not actual objects they seem to obey the laws of physics and often behave like actual objects (KOSSLYN ET AL., 1995). The ability to imagine an internal mental representation of the world is one of the most important bases to control thought and action and is essential in every day life by helping to solve problems and to conduct planned actions. Mental imagery is able to solve sensory ambiguity and has been shown to trigger the same brain areas as physical counterparts (e.g. COHEN ET AL., 1996, also see chapter on Mental Rotation and Motor Activity, page 23). A second central significance relies on our knowledge on spatial information. Spatial representations play a major role for motor planning (KOSSLYN, 1994). Geometry, architecture, and mental training are only a few examples which show how spatial-cognitive abilities allow mental testing and anticipation of actions. The term *spatial cognition* contains the acquisition and revision of knowledge on spatial surroundings as well as the handling of this knowledge and spatial imagery. In the early 20th century, psychometric investigation of spatial notion began and "spatial abilities" were analyzed more closely with the introduction of the multiple factor analysis. THURSTONE (1938) defines seven primary factors of intelligence, one of them being spatial knowledge. Spatial orientation refers to the ability to imagine and visualize the appearance of objects in different orientations and views (HEGARTY & WALLER, 2004). Mind, brain and body interact to construct our experience of space and therefore with our physical and social environment (ROHRER, 2006).

Important insights on the process of mental rotation and other imagery processes come from PET and fMRI studies. Imaging techniques allow investigation of distinct brain activities and neuronal connections and mechanisms. Mental rotation obviously seems to rely on a different neural network than when an image is generated or looked at (e.g. COHEN ET AL., 1996; PARSONS & FOX, 1998). Yet, various studies report activity in primary visual areas 17, 18 during visual mental imagery even when eyes are closed (for a review, see KOSSLYN & THOMPSON, 2003). This can be regarded as image-like storage of representations.

Imagery Debate

The nature of visual object representation in the brain has been a matter of prolonged debate. The computationalist and functionalist views held that the mind operates in a symbolic rather than depictive fashion, and therefore argued that any such mental imagery would be merely epiphenomenal (PYLYSHYN, 1973). Over the following years a variety of convergent evidence has established not only the fact that mental images are rotated in the brain as perceptual wholes (KOSSLYN ET AL., 1995), but have also specified how that fact impacts our understanding of exactly how our minds are "computing" (reviewed in KOSSLYN, 1994; KOSSLYN, GANIS & THOMPSON, 2001).

The picture theory by STEPHEN KOSSLYN (1980, 1994) relies on *analogue* (picturesque) *representations* and their storage in a specific visual system. The mind's eye interprets what we see. KOSSLYN AND THOMPSON (2003) use the term *visual mental imagery* when relating to a mental image that is represented in short-term memory without an according object being there in reality. Despite all their similarities, mental images are not exactly the same as visual perceptions of the real world. Mental images are influenced by our memories and other mental processes. Our memories of objects are sometimes subject to errors, such as changes due to false suggestions. There is no physical aspect to a mental image, no absolute stimulus held in mind. Rather, mental images are part of our subjective perceptions of the world, representing only what the world looks like to us.

Some researchers (PETERSON ET AL., 1992) found that ambiguous pictures, like the one below (see Figure 26), cannot be reinterpreted once they are entered into memory and become mental images. If we first see the image as a rabbit, our mental image will show only a rabbit; we will never be able to see it as a duck by re-examining our mental image (and vice versa). A study by MAST AND KOSSLYN (2002) however challenges this view by studying mental imagery of ambiguous face figures which needs to be inverted to allow finding the inverted alternate version (see Figure 26, bottom). The authors argue that this new interpretation is hardly noticeable without prior experience and requires a new interpretation of image components and a new reference frame. The authors found that alternate interpretations can indeed be discovered in mental images, however not all participants were able to perform this task. In their study 16 out of 36 were able to

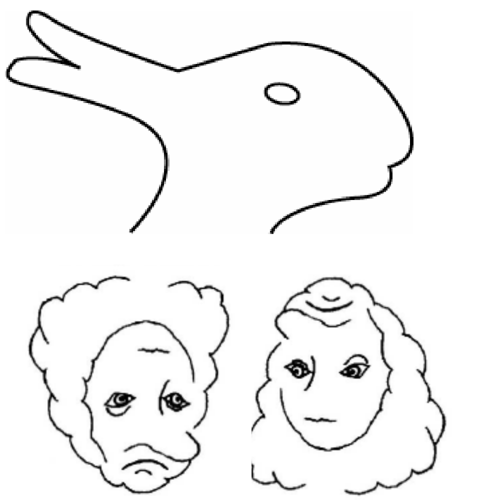

Figure 26 Ambiguous pictures: TOP: Rabbit or duck? BOTTOM: old or young woman? (MAST & KOSSLYN, 2002)

discover the alternate interpretation. These participants were also generally better at mentally rotating images as measured independently with different tests on mental imagery ability.

PYLYSHYN has long been the leading critic of "pictorial" theories of imagery (such as KOSSLYN'S). PYLYSHYN'S description Theory (1973, 1981) is based on the idea that the process of imagining an object is set together out of semantic (descriptive, propositional) representations that are formally stored in a central system subordinate to cognitive processes. Subjective image-like sensations are therefore merely epiphenomena based on descriptive knowledge. The Dual coding theory (DCT) by PAIVIO (1971, 1986) states, that there are two distinct systems for verbal and visual information. Experiments show that verbal information is stored more easily when concurrent visual images were generated along with them.

Mental Rotation

Mental rotation is a process that allows one representation to be compared with another (e.g., KOSSLYN & THOMPSON, 2003). Different types of mental imagery can be investigated with different tasks. The mind's eye can transform, manipulate, process, zoom in to or rotate objects. Depending on whether mental manipulation is necessary, physical laws (consciously or unconsciously) can be overridden or taken into account (size, shape, structure, material, color, distance etc.). Different types of mental spatial transformations require updating of three different spatial frames of reference: the intrinsic frame of reference of objects, the egocentric frame of reference depending on one's body (or body parts) and also an allocentric frame of reference referring to spatial coordinates (e.g. HEGARTY & WALLER, 2004; ZACKS ET AL., 2000).

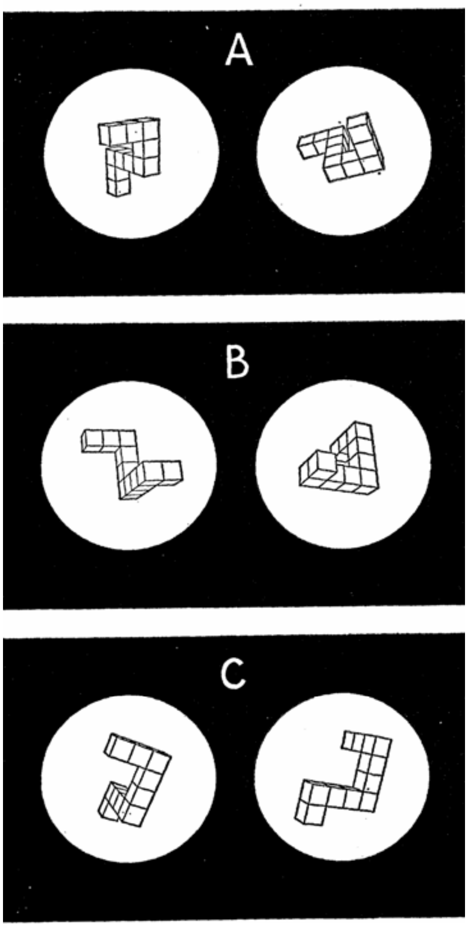

Figure 27 Examples of pairs of perspective line drawings presented to the subjects. **A:** "same" pair, which differs by an 80° rotation in the picture plane; **B:** a "same" pair, which differs by an 80° rotation in depth (YAW); and **C:** a "different" pair, which cannot be brought into congruence by any rotation. (SHEPARD & METZLER, 1971)

Research on mental rotation has been based on using *letters* or *numbers* (COOPER & SHEPARD, 1973; HINTON & PARSONS, 1981), abstract two- and three dimensional *shapes* (e.g. SHEPARD & METZLER, 1971), *objects* (familiar or unfamiliar; COOPER, 1975) or *human bodies* (bodies, mostly sketches, faces, body parts; PARSONS, 1987A & B). Mental rotation of complex objects as described by SHEPARD AND METZLER (1971) is one of the most investigated mental imagery task (COHEN ET AL. 1996). In their renowned experiment participants are asked to determine whether a two-dimensional drawing of a three-dimensional object (perspective line drawings) is identical to or a mirror image of another (see Figure 27). They found that subjects mentally rotate the object at a linear rate with increasing angular disparity – about 60 degrees per second (for both, picture and depth plane rotations). In other words, participants were manipulating such images as wholes, preserving their topologies while rotating them through a series of intermediate depictions (this contradicts the view of PERRETT, ORAM & ASHBRIDGE, 1998, see page 23). The authors conclude that mental rotation of an object simulates a physical movement in reality, and reaction time – as a linear function of angle of rotation – seems to be similar to a rotation in the physical world with constant velocity (COOPER & SHEPARD, 1973; SHEPARD & METZLER, 1971). Many investigations followed up on this matter and postulate analogue mental rotation and transformation processes. In an experiment by KOSSLYN, BALL AND REISER (1978) the time to scan a mentally stored image of a display (such as a fictitious island with landmarks) matched the time it took to scan an actual picture, even though prevailing information-processing theories suggested that mental encoding of the displays could eliminate the spatial relations. Mental scanning time from one object to another increases in proportion to the distance between the two objects, just as visual scanning time does with objects in the real world. This suggests that scenes and objects in mental images are represented in a way similar to scenes and objects in the real visual world.

BAUER AND JOLICOEUR (1996) mention three factors that are responsible for slope and intercept of the typical RT-function across different angular disparities: 1. *complexity*: they assume that the more complex the stimulus, the steeper the slope relative to angular disparity (not confirmed by some studies), 2. The *nature of presentation*: simultaneous presentation of stimuli (same-different task: simultaneous comparison of two stimuli) leads to a larger slope than sequential presentation (left-right decision task: comparison with internal representation) and 3. the *dimensionality of stimuli*: There are controversial results in literature when comparing 2-dimensional with 3-dimensional objects. BAUER AND JOLICOEUR (1996) investigate the effect of dimensionality and find that 3D objects indeed elicited steeper slopes than 2-d objects and also found significantly different error rates in the two conditions. KOSSLYN (1980) postulates the following model: the system of mental rotation is noisy and therefore features a clean-up mechanism. The larger the angular disparity from the upright position is, the larger the susceptibility to noise. BAUER AND JOLICOEUR (1996) interpret their data using this model: to avoid decay of the object representation due to this noise during rotation it is recorded in regular intervals. Due to the fact that these momentary representations are subject to noise in more dimensions, they need to be stored more often which leads to higher reaction times.

Recognition versus Mental Rotation

PERRETT, ORAM AND ASHBRIDGE (1998) disagree with the view that mental rotation actually takes place. They examined the responses of populations of neurons recorded from the STS of macaque monkeys and found that different cells are tuned to different views (95% cells selective for view, 5% respond to all views; PERRETT ET AL., 1991). There are statistically more cells coded for face and profile views. These are preferentially coded characteristic views that are also found to be important psychologically (see Figure 28). According to LOGOTHETIS AND PAULS (1995) there is a neural coding of orientation where most cells (approx. 75%) are selective for orientation, different cells tuned to different orientations; most cells, approximately 70% to upright (frequently experienced situation), most are tuned to trained orientation, a minority (ca. 25%) respond to all orientations. It remains an open question as to how fast or with how much "training" cells start being tuned to unfamiliar orientations.

PERRETT ET AL. (1998) provide an explanation of the variation in speed of recognition across different viewing circumstances seen in behavioral studies; the speed of recognition of an object depends on the rate of accumulation of activity from neurons selective for the object, evoked by a particular viewing circumstances. Unfamiliar views will cause fewer cells to activate or accumulate (threshold is reached slower) and this fact accounts for the increased time to recognize rotated views without the need to postulate "mental rotation/alignment" or "transformations" of novel views to align with neural representations of familiar views. The authors also criticize that the increase of reaction times to unfamiliar views is too low for mental rotation. They believe that the decrease of reaction times through practice speaks in favor of their theory. These practice effects are well known and have been reported by others (e.g. HEIL ET AL., 1998). MURRAY ET AL. (1993) however adhere to the fact that the pattern of reaction times ("RT-image") stays the same yet at a lower level. TARR AND GAUTHIER (1998) suggest that training across few conditions enhances recognition of only those views close to the training views and has little benefit for far away views; this effect is interpreted as forming new viewer-centered representations (TARR & GAUTHIER, 1998).

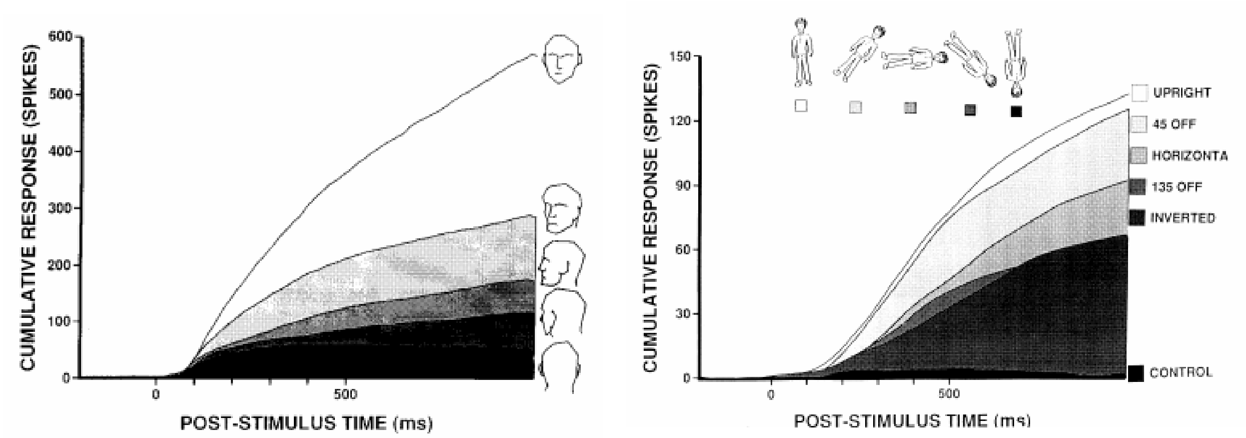

Figure 28 Coding of perspective view in STS; **LEFT:** Effect of rotation from face view on the time course of cell responses: cumulative neuronal activity (spikes) above spontaneous activity. **RIGHT:** Effect of orientation on the time course of cell responses: the cumulative difference in response from spontaneous activity of 11 cells selectively activated by the sight of the head and body (WACHSMUTH ET AL., 1994). The 11 cells were selected on the basis that they had each been tested with eight face orientations and responded to one or more orientation at rates above control stimuli and spontaneous activity. The cells were chosen independent of their orientation tuning (most responded best to upright orientations but some responded best to non-upright orientations). Data are plotted for five stimulus orientations expressed as the angle from upright and control stimuli. (PERRETT ET AL. 1998)

BAR (2001) suggests that it is conceivable that viewpoint dependency reflects the utilization of neural paths with different levels of sensitivity en route to the same representation, rather than the existence of viewpoint-specific representations and suggests new experimental paradigms to study the validity of the viewer-centered approach.

Body Image

Our "body-image" is quite inseparable from the activity of the cognitive subject. The notion that the "mind" is intrinsically "embodied" has been developed explicitly and at length by VARELA (1993), and ROHRER (2006) gives a good overview of the term. STEWART (1996) cites clinical evidence to support that basic self-awareness depends on what he calls a "body-image". This body image provides an indispensable reference for making sense of perceptual experience, for example with the phenomenon of "hemi-neglect" in which a cerebral lesion leads to a paralysis of one side of the body of which the patient himself is not aware. DAMASIO ET AL. (1994) supports this kind of interpretation, and add evidence from functional neuroanatomy. It is interesting to note that this line of work supports the openly expressed opinion of SEARLE (1992), who holds that the brain does not contain "symbols" susceptible to syntaxical manipulation and even less "homunculi", but only neurons which, by virtue of their configurations of activity, establish significant relations. One of the results of such constructions is the emergence of a body as such; it is significant that we speak of the "bodies" of animals, but not of plants (even though research has shown that depending on task, embodiment can also be applied for non-living objects). Research by CREEM, WRAGA AND PROFITT (2001B) showed that imagining the rotation of "your own hand" yielded higher accuracy and lower reaction times as opposed to the condition where participants were to imagine "a hand". Recognizing a visually presented right or left hand appears to be achieved through mental reaching, as if we imagined our own hand matching the visually presented hand (PARSONS, 1994, 1995). Therefore, a left-right decision task involving bodies or body parts seem to trigger a mental motor simulation strategy, consisting of mentally matching the observed hand with our own hand (PARSONS, 1987B, 1994, also see next chapter on Mental Rotation and Motor Activity).

Axes of Rotation

Previous studies show that reaction times strongly depend on the *axes of rotation* (e.g. depth vs. picture plane[14])(MURRAY, 1997; PARSONS, 1987A; PARSONS, 1995). PARSONS (1987A, 1987B) did extensive research on how people are able to imagine their own body rotating in space. He thoroughly studied egocentric transformations, testing body parts (1987B) and human bodies (1987A) in a variety of different rotating axes and found that the extent of angle of rotation from the upright orientation leads to different results. Parsons concludes that spatial transformations vary strongly depending on *different axes* and *directions of rotation* about an axis. PARSONS (1987A) suggested three possible procedures of mental rotation: 1. *Rotations-by-dimensions*: a "decomposition" procedure producing a sequence of rotations about a different axis (e.g. a principal axis of the object or environment) for each dimension by which they differ in orientation. 2. *Spin-precession*: rotation about an instantaneously changing axis produced by simultaneous rotations about two orthogonal axes (e.g. a principal axis of the object and an axis fixed in the environment, as in a spinning top or celestial body). 3. *Shortest path*: rotation about an axis (unique for each orientation difference) to simultaneously correct for all differences in orientation while absolutely minimizing the degrees of rotation. Parsons could not rule out any of these procedures, however his data clearly did not support the inefficient rotation by dimension (1.) and fitted better to his latter two suggestions. PARSONS (1994) also reported that the *temporal* and *kinematic* properties of imagined spatial transformations are more object-specific than previously assumed. When people imagine parts of their bodies such as their hands and feet moving in space it shows that they imagine hands and feet moving in paths that are physically possible (PARSONS, 1994) and show inferior performance when they have to imagine "unnatural" awkward movements. PARSONS found lower reaction times for mental rotation of line drawings of bodies compared to objects used by SHEPARD AND METZLER. A similar effect of decreased reaction times showed when the three-dimensional SHEPARD-METZLER objects are presented with a head (AMORIM, ISABLEU & JARRAYA, 2006). Mental rotation of body-like objects seems easier (less errors) and faster (lower RT) than abstract 3D objects. Is it possible that familiar manipulative objects also trigger such an egocentric

[14] These terms have been used differently to our study (see Figure 29)

transformation process? Shape matching with the human body turns out to be a cognitive advantage (AMORIM ET AL., 2006) and motor activation has been reported even when participants mentally transform nonbody objects (e.g. COHEN ET AL., 1996 (SHEPARD-METZLER objects), VINGERHOETS ET AL., 2001). The body image is an essential internal representation with an innate system of reference ready at all times (up-down, left-right, back-front). JOLA AND MAST (2005) also show that it is easier to rotate a human figure than SHEPARD-METZLER objects (adapted in orientation/difficulty). They however stress that these are two different tasks (mental object rotation task vs. mental body transformation task, see chapter on Multiple Spatial Systems, page 23). Extremities can easily be rotated the way traditional SHEPARD-METZLER objects are when they are presented isolated and this process is not disturbed by other factors such as the presence of other extremities or tools (PETIT ET AL., 2003). Many authors suggest that two distinct processes are at play: participants either imagine their hand moving (motor imagery) or they recall the image of a hand from memory as an external object (visual imagery) (e.g. DE'SPERATI & STUCCHI, 2000). As for rotation of a hand at an incompatible position the former strategy (first person instruction, e.g. "imagine yourself looking at the back of your left hand, fingers pointing down") leads to faster response than a third-person instruction ("imagine yourself looking at the back of my left hand, fingers pointing down") (SIRIGU & DUHAMEL, 2001). Interestingly, the authors found improved performance for third-person instruction when participants were to hold hands behind their backs ("incompatible posture") suggesting that it is processed "detached" from the body. For same-different tasks imagined movement seems to be more important (WEXLER, KOSSLYN & BERTHOZ, 1998; WOHLSCHLÄGER & WOHLSCHLÄGER, 1998; ZACKS ET AL., 2000).

When people imagine objects rotating in space they are more accurate when the objects are *aligned with horizontal and vertical*, a result reminiscent of rotation to frame of reference in mental representation of space (PANI ET AL., 1996). Thus, mental transformations are biased in at least two ways: toward transformations that are possible in the *physical and biological* world and toward transformations that are *aligned with the horizontal and vertical axes* of the world (ZACKS & TVERSKY, 2005). In line with this, MURRAY (1997) showed that participants use different strategies while performing the task, such as efficiently flipping an inverted stimulus to the upright opposite to spinning it back.

Interestingly, response times are also longer if the to-be-imagined position is misaligned with the participant's actual position (AMORIM & STUCCHI, 1997; CREEM ET AL., 2001B; PARSONS, 1987A; PRESSON, 1982, PRESSON & MONTELLO, 1994, WANG & SIMONS, 1999, ZACKS, VETTEL & MICHELON, 2003). This has been interpreted as the use of analogue perspective transformations, which update the location and/or orientation of one's egocentric perspective.

Mental Rotation and Motor Activity

In 1934, an author named Kate Gordon reported an experiment meant to study empathy and made an interesting observation quite relevant to today's research in mental rotation.

"*The idea of empathy also has relation to those theories of perception which hold that our motor response helps us to interpret the object.*" (GORDON, 1934, p.893*)*

The author used the statue of a little Mexican image showing a figure with one arm lifted in the air. She observed that some persons showed marked gesticulations before they could answer the question of which arm is extended. Others showed slight movements of the hands, and some, whose movement is not publicly perceptible, report that they were aware of the twitching of their muscles (GORDON, 1934).

Several studies have shown that mental rotation is influenced by motor activity and considers planning of action (E.G. KOSSLYN, 1994; WEXLER ET AL., 1998). Imagery draws on mechanisms used not only in perception, but also in motor control (KOSSLYN ET AL., 1995). It has been proposed that understanding an observed action such as grasping an object involves an internal motor model of that action (DE'SPERATI & STUCCHI, 1997). The execution of a manual rotation in the same spatial axis and with the same direction as a mental rotation leads to faster reaction times than when manual and mental rotation are incongruent or incompatible (DE'SPERATI & STUCCHI, 1997; WEXLER ET AL., 1998; WOHLSCHLÄGER & WOHLSCHLÄGER, 1998). WEXLER ET AL. (1998) describe mental rotation as a covert simulation of motor rotation. Instead of conducting a real rotation with hand or head, we plan an action but do not overtly execute it; a perceivable result of a planned action is simulated and visuo-motor anticipation therefore controls mental rotation (premotor areas). Such empirical and theoretical criteria suggest that perception is strongly influenced by the biomechanical laws of the body, which themselves are involved in imagery processes (PETIT ET AL., 2003, ALSO SEE PARSONS, 1987A). DE'SPERATI AND STUCCHI (1997) tested left- and right-handed subjects in a task that required to imagine their dominant or non-dominant hand grasping a screw-driver and recognize its motion (screwing or unscrewing). Interestingly, they did not find an influence of what hand was giving the responses, but reaction times were significantly higher for the condition where right-handers were to imagine their left hand doing the screwing motion in contrary to when they were to imagine doing this with their dominant hand. They conclude that some cognitive functions for space processing are similarly lateralized in right-handed and left-handed subjects and that objects that can be manipulated may be cognitively processed also in relation to our manual dominance. The also find response times to be a function of the "graspability" of the visual stimulus.

Neuro-imaging studies of mental image transformations have sometimes implicated motor processes and sometimes not (KOSSLYN, GANIS & THOMPSON, 2001). Motor cortex (including area M1) was found to be activated only when subjects imagined the rotations as a consequence of manual activity. Thus, there are at least two, qualitatively distinct, ways to imagine objects rotating in images, and these different strategies can be adopted voluntarily. A study by WRAGA ET AL. (2003) however showed that an implicit transfer of motor activation can occur in a mental rotation task of objects (SHEPARD-METZLER objects) when the preceding condition is to mentally rotate hands. This shows in a more decreased RT and more accurate performance in the object task following the hand task even when participants are not explicitly instructed to imaging rotating the object with their hands. This adaptation of motor strategies from the egocentric hand rotation task can therefore be transcribed to the objects (DE'SPERATI & STUCCHI, 1997; PETIT ET AL., 2003; WRAGA ET AL., 2003).

The involvement of motor areas has also been shown in various mental object rotation tasks (e.g. KOSSLYN ET AL., 1998) but their roles in mental body rotation is not yet clear (ZACKS ET AL., 2002). It is possible that mental body rotation requires rotating individual body parts separately rather than a rigid rotation to reorient the entire body with the stimulus. In this context the questions arises if mental transformation processes are conducted in a rather analytical (piecemeal, component, feature) versus holistic rotation (AMORIM ET AL., 2006). Detailed investigations on mental rotation show that for the execution both of these processes can be applied. Analytical rotation means that objects are composed of several segments that are associated with each other and that these are represented and processed. Holistic rotation regards the object as a whole, non-differentiated unit and is less influenced by detailed input, it is less demanding, and transient but also less flexibly applied (DROR, SCHMITZ-WILLIAMS & SMITH, 2005).

Much evidence for the coupling of action and mental rotation derives from studies on mental rotation of body parts, especially when hands are investigated (KOSSLYN ET AL., 1998; PARSONS, 1987B). PARSONS (1987B) investigated imagined spatial transformations with left-right judgments of hands and feet. In his study participants imagined simulating movements of their own body parts from a starting orientation and body position to the orientation of the stimulus. The less natural the orientation, the more time was required for the mental transformation of ones own body part. The pattern of reaction times showed a preference for "possible directions" of effective movements. This indicates that judgments of participants are based on a mental analogy including kinesthetic and/or proprioceptive information related to real movements. A study by FRICK ET AL. (2005) also showed that incompatible manual rotation during mental rotation leads to higher reaction times, yet this effect decreases with age (they studied 5-, 8-, 11- year old children and adults). This finding suggests that skills for a partial decoupling of visual and motor activities develop with age. Patients with an injured arm have also been shown to be slower when mentally rotating pictures of a hand of the same side as the hurt one (SCHWOEBEL ET AL., 2001). Representations of the body therefore seem to be the implicit functional basis for motor activity (KOURTZI & SHIFFRAR, 1999). The motor imagery system actively determines how fast such mental imagery is executed (ROHRER, 2006). In literature this is referred to as a return to the body to cognitive science (embodiment). Participants report that mental rotation of body parts are strongly subject to anatomical constraints and that positions that are physically difficult or impossible are harder to rotate (PARSONS, 1987B; PETIT ET AL., 2003; SEKIYAMA, 1982). Participants seem to apply a set of mental transformations that mimic a real hand movement. When participants are asked a left-right judgment of a hand, as mentioned before reaction times vary systematically according to the hand-specific limitations of the joint (PARSONS, 1987B). In other words, reaction times are higher for the positions of the hand that are not easily reached (SEKIYAMA, 1982).

FMRI studies also mention activation of motor areas during some mental rotation tasks. Participants show activity in premotor area (PMA) and in the primary motor cortex (M1). These regions seem to be the most important regions involved during spatial transformations (WINDISCHBERGER ET AL., 2003). PARSONS ET AL. (1995) examined brain activity of 16 participants during mental rotation with PET (left-right task with hands). During such an egocentric task (hand-to-hand) the authors find activity in brain areas dedicated to motor control. KOSSLYN ET AL. (1998) compares executions of same-different tasks with line drawings of hands and SHEPARD-METZLER objects. Activity in motor and premotor areas is recorded during hand rotation but not during mental rotation of the objects, for example when participants relate the presented hands to their own. There are differences in brain activity when subjects rotate either non-biological or human figures (e.g. BLANKE ET AL., 2005; ZACKS ET AL., 1999, 2003).

The research findings on activity of visual and motor areas during mental rotation emphasize the flexibility of spatial transformation mechanisms. (WRAGA ET AL., 2003). Depending on the nature of task, different aspects of the system are important and therefore play a major role in the final action. WRAGA ET AL. (2003) suggest that mental rotation tasks involving body parts elicit motor strategies where activation of premotor area PMA and primary motor cortex M1 is found during mental rotation. Many of these studies require participants to mentally transform body parts (e.g. PET studies: KOSSLYN ET AL., 1998; PARSONS ET AL., 1995 or TMS studies: GANIS ET AL., 2000).

First-person imagery involves motor activation while third-person imagery relies primarily on non-motor mechanisms. Activation of covert motor and visual processes during mental imagery relies on top-down as well as on bottom-up factors (SIRIGU & DUHAMEL, 2001). The authors compare data of healthy participants with those of patients with parietal damage and their results show that the coupling of visual and motor processes during mental rotation relies on the parietal lobe areas. This area is critical for the activation of covert motor processes during simulated motor actions. Their study shows that intact visual imagery is sufficient for mental rotation, yet when there is an impairment of the parietal lobule, mechanisms of visual and motor imagery can no longer be coupled[15].

Motor strategies are not defined by their reliance on mental rotation of a body-related stimulus per se, but rather may be defined as strategies that can be used in tasks requiring egocentric transformations (WRAGA ET AL., 2003).

Multiple Spatial Systems

Evidence is accumulating that multiple systems compute different classes of mental spatial transformations (E.G. MICHELON & ZACKS, 2006; PRESSON, 1982; ZACKS ET AL., 1999; ZACKS ET AL., 2002; ZACKS & TVERSKY, 2005). Some studies demonstrate both cognitive and neural distinctions between spatial decision tasks involving egocentric and object-relative spatial transformations (CREEM ET AL., 2001A; KOSSLYN ET AL., 2001; WRAGA, CREEM & PROFITT, 2000; ZACKS ET AL., 1999). Other authors have also suggested that object rotations and self-rotations depend on different neural structures (CREEM ET AL., 2001A; ZACKS ET AL., 2002). ZACKS ET AL. (1999) investigated these two "distinct systems" with fMRI and confirmed the dissociation between egocentric perspective transformations and object-based spatial transformation such as mental rotation with specialized activation of areas.

The two processes distinguished here are referred to as *object-based spatial transformation* – imagined rotations or translations of objects in space – and *egocentric perspective transformation* – imagined transformations of one's own perspective (e.g. KRULL ET AL., 2003)[16]. Previous research has made this clear distinction between tasks that investigate object-based spatial transformations or those focusing on egocentric spatial transformation (HEGARTY & WALLER, 2004; JOLA & MAST, 2005; RIGAL, 1996; WRAGA, CREEM & PROFFITT, 2000; ZACKS ET AL., 2000). In the context of egocentric spatial updating, imagined viewer rotations have been shown to be performed more easily than imagined object rotations (AMORIM & STUCCHI, 1997; CREEM ET AL., 2001B; PRESSON, 1982; WRAGA ET AL., 1999; WRAGA ET AL., 2000). CARPENTER AND PROFITT (2001) found that the viewer advantage only occurred in the transverse plane (rotation about z-axis).

Many authors assume that visual representations of the human body depend on perspective (KOURTZI & SHIFFRAR, 1999). A typical experimental situation is when participants are asked about

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[15] Also compare with PARSONS, 1987B (unnatural hand positions lead to higher reaction times).

[16] This distinction has also been made in object recognition where authors divide into object-centered recognition (e.g. MARR & NISHIHARA, 1978; BIEDERMAN, 1987) or view-centered recognition (e.g. ULLMAN, 1989; POGGIO & EDELMAN, 1990; TARR & GAUTHIER, 1998).

the array of objects after they have imagined themselves or the objects rotate. Results for object or self rotation differ in difficulty level. This level relies on factors such as *how the question is asked*, the *number of objects* (single or array) to be rotated (WRAGA ET AL., 2000) and whether or not people physically *move themselves or the object/array* while mentally imagining the spatial transformation (HEGARTY & WALLER, 2004; KOSSLYN ET AL., 2001). As mentioned, tasks requiring object rotations and self-rotations produce different response time profiles. Object rotations show a linear increase in response time as a function of angular disparity (e.g. SHEPARD & METZLER, 1971), whereas self-rotations do not always show this pattern or angular disparity effect (WRAGA ET AL., 2000; ZACKS ET AL., 2000). It has been shown that participants are more efficient when conducting a mental self-rotation compared to rotation of the surrounding (WRAGA ET AL., 2000). This is remarkable because both rotation processes rely on the same visual transformations (CARPENTER & PROFFITT, 2001). These studies offer different explanatory models for human spatial representation. It has to be considered however, that tasks involving change of perspective are different to the traditional mental rotation tasks; they measure judgment of relative spatial directions instead of applying object recognition tasks; they involve imagined movements of the subject itself as well as of the object and apply an array of objects surrounding the observer.

There are two ways to imagine what an object looks like from a different viewpoint without actually moving. Imagining the object rotating until the desired viewpoint is aligned with the current perspective of the observer or imagining oneself moving around the object to a new view point. Both kinds of transformations are important in everyday tasks of spatial reasoning and both require the representation of a different spatial frame of reference: egocentric self rotations involve transformation of the *egocentric frame of reference* (relative to intrinsic axes of observer's body). Imagined object rotations involve *transformation of the object-relative frame* (location of an object's parts with respect to each other) (WRAGA ET AL., 2005).

Does object-centered transformation incorporate the environment, such as gravitational cues while egocentric transformation only relies on perception of presented figure relative to us?

Experiments

There is a wealth of knowledge in the research area of mental transformation. It is clear that mental rotation tasks as investigated here always imply cognitive (top-down) as well as perceptual (bottom-up) processes; however the specific aims and objectives of the following experiment are:

Focus on Perceptual Influence on Mental Rotation

EXP POS-PICT and EXP POS-DEPTH: Gravitation and cognition

As mentioned in the introduction, the term "cognition" here describes high-level, top-down processes. "Perceptual" on the other hand relates to low-level, bottom-up processes provided by bodily sensors such as graviceptors in the vestibular system. Can subjective perception of orientation alter or even improve mental imagery? Is our body position able to "unconsciously" (bottom-up) influence mental rotation?

As mentioned in previous studies, response times are longer if the to-be-imagined position is misaligned with the participant's actual position (AMORIM & STUCCHI, 1997; CREEM ET AL., 2001B, PARSONS, 1987A; PRESSON, 1982, PRESSON & MONTELLO, 1994, SIRIGU & DUHAMEL, 2001; WANG &

SIMONS, 1999, ZACKS ET AL., 2003). This has been interpreted as the use of analogue perspective transformations which update the location and/or orientation of one's egocentric perspective.

How flexible can sensory information resources be used for mental rotation? Is less more (confusion) or does altered position lead to a facilitation in a mental rotation task of bodies?

Focus on Cognitive Influence on Mental Rotation

EXP PLANE: Body figures rotated in the picture vs. depth plane

How canonical is canonical[17]? Are there positions more familiar and therefore easier to recognize and respond to? Three-dimensional human figures in the depth plane (PITCH rotation about y-axis) are compared with rotation in the picture plane (ROLL rotation about x-axis).

EXP HANDSHAKE: Altered instruction and body figures

Some authors emphasize the influence of instruction in mental rotation experiments (e.g. BROCKMOLE & WANG, 2003; CREEM ET AL., 2001B; SIRIGU & DUHAMEL, 2001; ZACKS & TVERSKY, 2005). It is assumed that the type of task influences mental transformation processes by triggering egocentric (first-person) or more object-centered (third-person) transformations. In this allocentric task participants are to judge if the human figure is stretching out the correct or false hand for a correct handshake. This renders the front view of the figures easier compared to back view stimuli. This further allows to assess how this affects reaction times at different angular disparities in the picture and depth plane. Can the back-front view effect found in previous experiments be reversed?

EXP OBJEGO: Object vs. egocentric transformation

Earlier studies imply that characteristics of imagined spatial transformations of body figures are different to other objects (such as letters, numbers, two- or three-dimensional, abstract or unfamiliar shapes). Judgments of body figures usually lead to an egocentric transformation, while similar tasks with objects (such as letters; e.g. COOPER & SHEPARD, 1973; HINTON & PARSONS, 1981) usually evoke object-based transformation (ZACKS ET AL., 2000). PARSONS (1987A, 1987B) reported significantly lower reaction times for mental rotation of body figures in the picture plane compared to SHEPARD-METZLER objects. The body analogy seems to be an advantage favoring embodiment processes and evoke a body image. This influences transformation processes by giving them an advantage opposite to abstract objects (AMORIM ET AL., 2006).

Recent research has also demonstrated the importance of imagined body movements for spatial judgment tasks about manipulable and graspable objects (DE'SPERATI & STUCCHI, 2000; KOSSLYN ET AL., 2001; WEXLER ET AL., 1998; WOHLSCHLÄGER & WOHLSCHLÄGER, 1998). This experiment directly compares an object-centered (applying left-right judgment of camera) with an egocentric (applying left-right judgment of a human body) task.

[17] The term canonical comes from the Arabic word "Qanuun" which means "rule", "law", "standard". A canonical view is the most common view of an object where it is recognized the fastest (GOLDSTEIN, 2002).

EXP 5: 3D

Left-right discrimination is essentially dependent on perspective. Perspectives which do not correspond directly sometimes afford mental operations to discriminate left from right (RIGAL, 1996). In contrary to PARSONS (1987A), ZACKS ET AL. (2000) apply only front view stimuli (figure facing the observer). In what they refer to as the egocentric perspective transformation (left-right decision task) the authors do not find orientation effects. Reaction times are high and constant for front view body figures. This implies that egocentric judgment in a left-right task with rotated human figures is independent of angular disparity. PARSON'S data (1987A, 1987B) do not conform to this view. In his study on body or body part transformation reaction times are always dependent of how far orientation of a figure deviates from the orientation of the observer and on the different axes of rotation. This experiment aims at expanding the investigated rotation angles with a naturalistic body figure.

General objectives in all of the experiments are the individual performance (are there different types of mental rotation strategies?) and expertise (general decrease of reaction time (RT) and error rates (ER) without changing the pattern of results?). With exception of EXP OBJEGO and EXP 3D participants do not receive instructions as to how they are to conduct their task (egocentric- vs. allocentric- vs. object-centered transformation).

Participants start the experiment the moment they press any of the two buttons of a serial mouse. They do not receive any feedback during the experiment. There are short breaks between the experimental conditions. After the experiment participants are asked to give a short impression of how difficult the task and condition was. However, with exception of EXP PLANE no standardized questionnaire is applied and reports were noted descriptively in a log book. In all of the experiments measures of response times (RT) as a function of angular disparity of stimulus orientation from its canonical orientation, error rates (ER), standard deviations (SD) and introspective reports served as data base and underwent analysis.

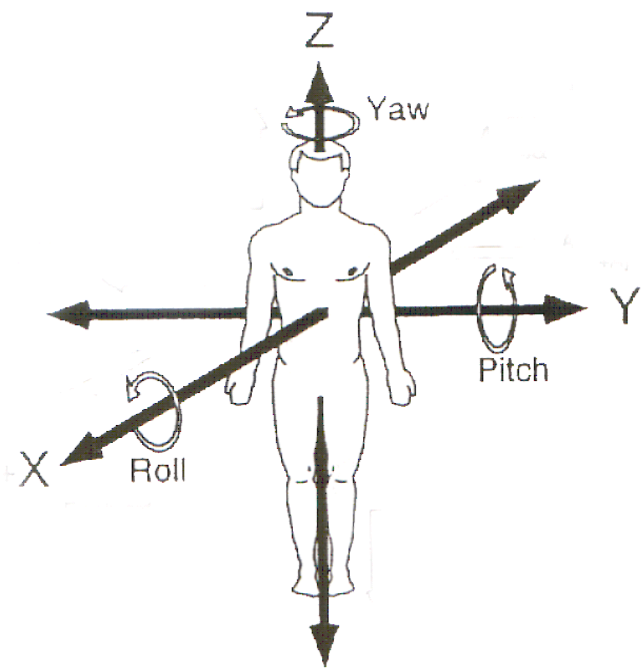

Figure 29 Spatial Coordinates shown for a front VIEW figure: Rotation about the x-Axis (ROLL) is equivalent to the PICTURE PLANE; angles of rotation are coded CW, rotation about the y-Axis (PITCH) is equivalent to the DEPTH PLANE; increasing angles of rotation are coded towards the front.

In the following experiments, angles of rotations of the stimuli are referred to the axis of rotation x (ROLL movement in the picture plane), y (PITCH movement in the depth plane) and z (YAW) (see Figure 29).

2. Mental Rotation of Body Figures in the Depth and Picture Plane

Abstract

How canonical is canonical? Are there body positions that are more familiar and therefore easier to recognize and respond to? The present study examines mental rotation of human figures in the depth (PITCH) and picture plane (ROLL). A left/right decision task is applied where participants are to decide whether the left or the right arm of the body figure is extended. Stimuli are presented in front and back view at eight different angles of rotation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°). Sixteen participants perform this task in two rotation conditions: body figures are either rotated in the picture plane or in the depth plane. Instead of line drawings of human bodies (as those used by PARSONS, 1987) pictures of a photorealistic rendered male body are used. Participants report using different strategies while performing the task and indicate that at large rotation angles they either just mentally flip the figures to the upright position or flip their own body from upright to the stimuli position. However, reaction times (RT) on average do not directly support corresponding statements. Nevertheless, a clear difference between the experimental conditions is visible showing a strong asymmetry for reaction times and standard deviations in the depth plane where RT peak at 225° instead of 180° as in the picture plane.

Introduction

How are body figures being rotated in different rotation planes represented in our heads? Several studies that used different stimuli have elucidated mental rotation, yet a major part of research with body figures has been done for figures rotated in the picture plane and showing in a frontal view (facing the observer). Some mental rotation studies on bodies (e.g. PARSONS, 1987A, 1987B) and objects (e.g. MURRAY, 1997) already showed that both the *orientation of the stimulus* and the *axis of rotation* are relevant factors. PARSONS (1987A) was the first to conduct a thorough investigation of different axes of rotation. He found different functions of reaction times dependent on angles of rotation for various axes which were different for clockwise and counterclockwise angles of rotation. His data reflected a tendency for reaction time to be longer for stimuli showing the top of the body pointing away from the observer and especially below the horizontal plane and away from the observer. PARSONS (1987A) concluded that people use different rotation paths for the same extent of angular disparity. This is consistent with his observations of imagined spatial transformations of hands and feet. Based on his data on body figure rotations, PARSONS (1987A) makes the following predictions; reaction times are increased when the head is oriented: 1. Away from the observer or forward, 2. Away from the observer and beneath the transversal plane, 3. Upside down (180°) and 4. Upside down with the body closely parallel to the frontal plane of the observer (135°, y-axis). Parsons also put emphasis on the fact that reaction time for a figure in an upside down position was dependent on its view (front/back). He stated that with less familiar upside down orientations it is possible that, people imagine less efficient paths, take longer to find a path, or produce slower imagined spatial transformation. Body rotations about the vertical (z) axis are common in our daily lives and this familiarity may increase the rate of imagined rotation. This training effect is also clearly visible in the decreased reaction times achieved with training in various mental rotation tasks (HEIL ET AL., 1998). Also METZLER (1973) reports that a rotation about the major principal axis of an object (here axis of elongation of the body) has been found to be more rapid than rotation about any other axes.

Some authors have reported longer reaction times if the to-be-imagined position is misaligned with the participant's actual position (AMORIM & STUCCHI, 1997; CREEM ET AL., 2001B), PRESSON, 1982, PRESSON & MONTELLO, 1994, WANG & SIMONS, 1999, WRAGA ET AL. 2000, ZACKS ET AL., 2003, PARSONS, 1987A). This has been interpreted as the use of analogue perspective transformations, which update the location and/or orientation of one's egocentric perspective. As TVERSKY, KIM & COHEN (1999) state "transformations that are difficult to do on real objects should also be difficult to do on described ones". Similarly, familiar objects in unusual views or novel orientations of trained shapes are difficult to recognize (ROCK, 1973; TARR & PINKER, 1989).

Based on PARSONS' findings (1987A) I expect that responses are not merely a strict rotation to a canonical orientation and therefore different results are expected for the two planes of rotation. The following experiment aims at investigating to what degree reaction times in the picture and depth plane rotation differ. An important difference to PARSONS in this study is that he refers to rotation about the z-axis (along the body axis) as a depth plane rotation while I refer to rotations about the y-axis with "depth plane". Visible body parts here strongly depend on what orientation the figure is presented at. Another point of interest is if different mental rotation strategies for figure rotations in the depth plane are evoked. Based on results reported by MURRAY (1997), we aim at triggering a "flipping" mechanism for inverted figures at 180° by offering them the "way to go" with the presented rotation angles in the depth plane condition. We expect reaction times for rotation angle 180° to be shorter – or at the same level, but not larger – in a depth plane condition as opposed to a picture plane condition.

Experiment PLANE

Method

Participants

Sixteen right-handed healthy volunteers participated in this study (8 female, mean age 30.6 years, range 22-37 years). All subjects had normal or corrected to normal vision and were naïve with regard to the hypothesis under investigation.

Material and Procedure

Human body figures (created by a 3D figure design program, Poser 6) are presented at eight different rotation angles (45° interval steps, coded clockwise for PICT and to the front for DEPTH) and in two different perspectives (front or back view). Each picture shows a human body with one arm (left or right) extended away from the body's midline and the other arm along the body's side (see Figure 30). Stimuli are presented with SuperLab Pro 2.0 (Cedrus Corporation, 1999). Each stimulus ANGLE of Rotation, VIEW and the number of left and right responses appears equally often and the order of presentation is randomized in nine consequent blocks and balanced throughout the experiment (=total of 288 stimuli ratings). Figures are presented on a flat screen

(PC Intel Pentium III processor, 750 MHz, 256 MB RAM with a resolution of 1024 X 768 pixels), mounted in front of the subject's head. A cardboard tube is attached to the screen leaving the participants viewing only a circular view of the screen. Eye to monitor distance is kept at a con-

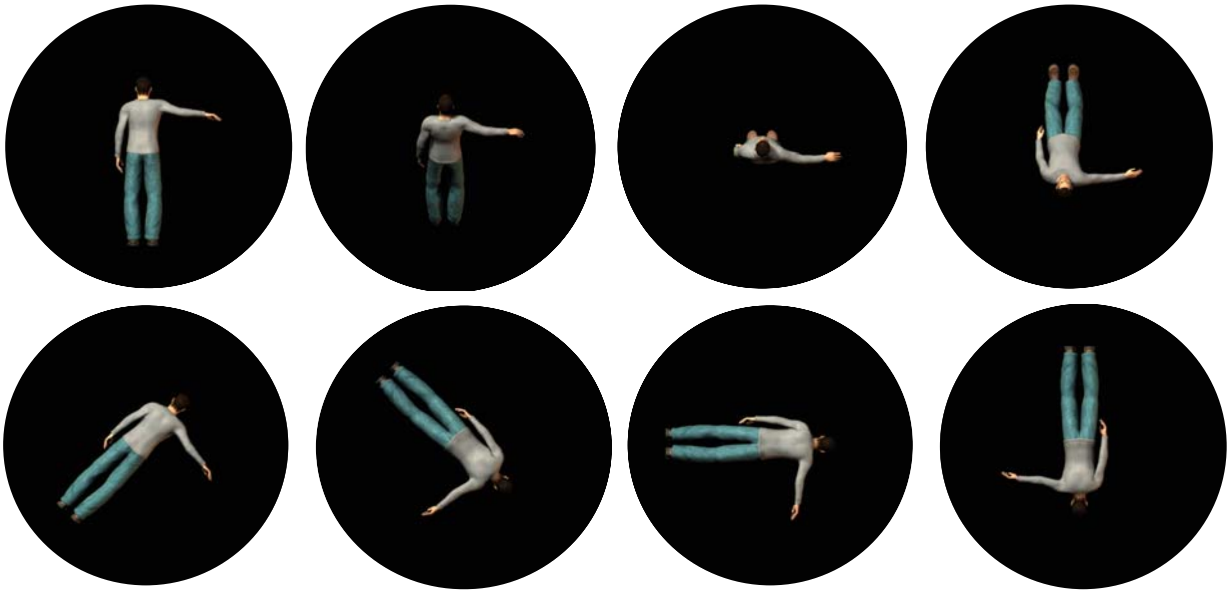

Figure 30 Human Body Figures, **TOP ROW:** rotation in the DEPTH PLANE (example given is a back-view figure at rotation angles 0°, 45°, 90°, 135°) **BOTTOM ROW:** rotation in the PICT PLANE (example given is a back-view figure at rotation angles 45°, 135°, 90° and 180°)

stant 40 cm which leads to an angle of vision of 15.7 degrees (when the figure is presented fully upright at 0°) with a stimuli size of 11cm. A chin rest ensures a stable position. The figures remain visible until the response is made and are followed by an inter-stimulus interval of 1000 ms.

The independent variables of the stimuli are SIDE (left, right arm), VIEW (front, back view), ANGLE of Rotation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), PLANE (DEPTH, PICT) and ORDER ($1^{st}/2^{nd}$ condition). The dependant variables are reaction times (RT) (measured by the participant's click on the according key of a serial mouse), standard deviation (SD) and error rates (ER).

Task. The participants' task is to decide which arm of the figure is extended (left-right discrimination). They press a button of a serial mouse with their left thumb if they think the figure's left arm was extended and they press with their right thumb if they think the figure's right arm is extended.

In a within design two experiment conditions are conducted and balanced throughout the experiment: Human body figures are rotated about the x-axis in the condition picture plane (PICT, see bottom of Figure 29) and are rotated about the y-axis in the condition depth plane (DEPTH, see top of Figure 29). All participants are made familiar with the task prior to the experiment by completing a short practice trial before each condition. They do not receive feedback regarding accuracy. For the following test trial, they are repeatedly encouraged to decide as quickly as possible while remaining as accurate as possible. The serial mouse is placed in both of their hands with their arms resting on the table.

The experiment takes about 35min (DEPTH plane condition takes significantly longer).

Results and Discussion

Data exclusion criteria:

- The cut-off criteria was set at 9s leading to an exclusion of only 0.1% (leading to practically the same amount of excluded data for both conditions (8 (PICT) vs. 10 (DEPTH) excluded responses).
- 4 persons only conducted seven (instead of nine) blocks in condition DEPTH (total of 224 responses instead of 288) because of a computer error.
- For RT analysis only correct responses are taken into account. Error rates were 6.2% (8.2% in condition DEPTH PLANE and 4.2% in condition PICT PLANE)
- F-values from ANOVAs lower than 1 ($F < 1$) were not interpreted because the variability within the conditions was higher than between conditions. A Greenhouse-Geisser correction was applied when Mauchly's W reached a significance level of $p < .05$.

Subjective Reports

The majority of subjects reported the depth plane condition to be much harder; this was clearly visible in the behavioral data showing significantly longer reaction times for this condition. Also, they report that they had a lot of trouble with the angle of rotation 225° in the depth plane and it took them noticeably longer to execute the task at this orientation.

Effect of Condition

Coding of rotation angles is arbitrary and not directly comparable between condition PICT and DEPTH, yet to allow direct comparison of conditions, angles to the left and right (PICT) as well as to the front and back (DEPTH) (45°-315°, 90°-270° and 135°-225°) are grouped and analyzed together[18] (see Figure 31). A separate individual analysis for both planes follows.

A three-way analysis of variance (ANOVA) with repeated measures with the within factors PLANE, VIEW and ANGLE was conducted and lead to the following results:

The factor PLANE did not yield significant effects in average RT ($F(1,15) = 2.62$, $p = .126$), yet revealed significance effects of **PLANE** for SD ($F(1,15) = 4.58$, $p < .05$, $\eta^2=.23$) and ER ($F(1,15) = 5.58$, $p < .05$, $\eta^2=.27$).

The main effect of the factor **VIEW**[19] was highly significant for average RT with $F(1,15) = 38.70$, $p < .001$, $\eta^2=.72$, for SD with $F(1,15) = 18.95$, $p < .01$, $\eta^2=.56$ but did not reach significance for the measure of ER ($F(1,15) = 2.20$, $p = .128$). The view-effect will be discussed in more detail in the separate analysis further down.

The main effect of the factor **ANGLE** was highly significant for average RT ($F(1.18, 17.72) = 34.35$, $p < .001$, $\eta^2=.70$) showing a general increase of RT with increasing angular disparity from

[18] A closer look at the DEPTH condition reveals that there is a strong asymmetry between frontward and backward positions which questions the grouping, therefore the two conditions are separately shown further down.

[19] It has to be considered that VIEW for Figures in the DEPTH PLANE rotation conditions does not relate to the same front and back as in the PICT PLANE since depth rotation leads to a "back-view figure" at 180°.

the upright position. This factor was also significant for SD ($F(1.80, 26.94) = 23.95$, $p < .001$, $\eta^2=.62$) and also for ER ($F(2.05, 30.80) = 9.13$, $p < .01$, $\eta^2=.38$)

There was a significant interaction between the factors **PLANE*ANGLE** for average RT ($F(1.86, 27.90) = 8.73$, $p < .01$, $\eta^2=.39$) for SD ($F(2.82, 42.24) = 11.59$, $p < .001$, $\eta^2=.44$) and for ER ($F(2.43, 36.49) = 7.14$, $p < .01$, $\eta^2=.32$). The interaction PLANE*VIEW did not reach significance (all $F < 1$). The interaction of the factors **VIEW*ANGLE** was significant for average RT ($F(4,60) = 11.76$, $p < .001$) for SD ($F(4,60) = 5.25$, $p < .01$, $\eta^2=.26$) but not for ER ($F(1.52, 22.74) = 1.28$, $p = 287$).

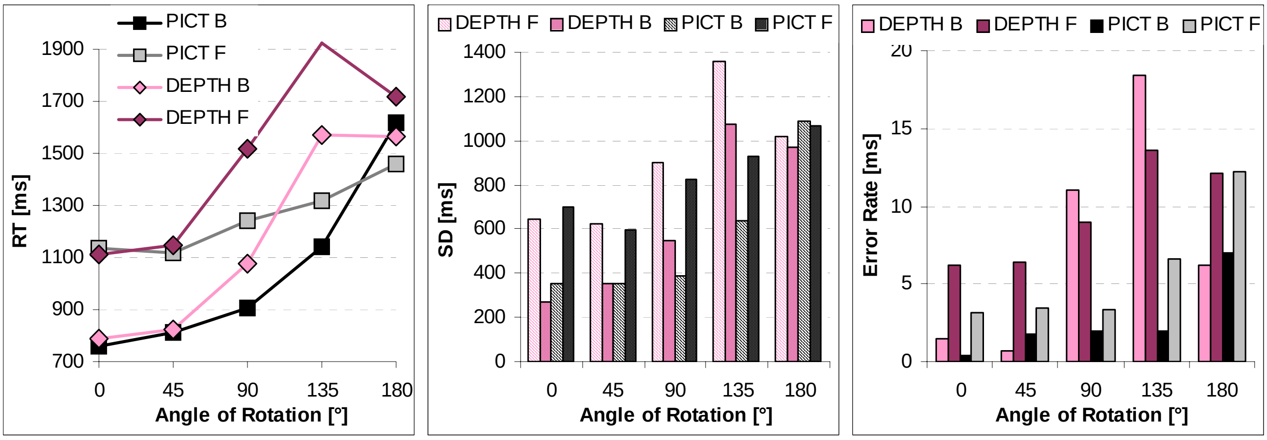

Figure 31 LEFT: average RT, **MIDDLE:** average SD and **RIGHT:** average Error Rate; shown separately for front and back view figures and with standardized ANGLES of rotation (front, back (DEPTH PLANE) and left, right (PICT PLANE) grouped together. (N=16)

Effect of Experience/Training/ORDER

An analysis of the **ORDER** of experimental sessions did not reveal significant training effects from the first condition to the second (RT; $t(15) = 1.53$, $p = .148$) however interestingly there was a significant improvement within the experimental session (first four blocks vs. last four blocks) for the DEPTH PLANE ($t(15) = 4.15$, $p < .01$) as well as for the PICT PLANE ($t(15) = 2.45$, $p < .05$) where the last four blocks always showed decreased RT. ER on the other hand did not significantly improve (less errors) in the course of the condition (both $p > .11$).

Separate Analysis of Planes

PICT PLANE

A two-way analysis of variance (ANOVA) with repeated measures with the within factors VIEW and ANGLE yielded a significant main effect of the factor **VIEW** for RT ($F(1,15) = 9.55$, $p < .01$, $\eta^2=.39$), for SD ($F(1,15) = 9.38$, $p < .01$, $\eta^2=.39$) and for ER ($F(1,15) = 6.54$, $p < .05$, $\eta^2=.30$). Response times for front view figures were generally higher than back view figures with exception of the upside down (180°) position, which showed an advantage of the back view figures. Error rates were generally low, yet participants made more mistakes with front view figures (8.7%, SD=9.2) than with the back view ER (3.8%, SD=3.0).

The view effect indicates that participants performed different mental transformation processes when stimuli were presented from the front or back (e.g. JOLA & MAST, 2005); the arrows in Figure 32 indicate the time presumably needed to make the additional YAW-rotation for FRONT stimuli.

The main factor **ANGLE** did also reach significance for RT ($F(1.20, 18.03) = 16.11$, $p < .001$, $\eta^2=.52$), for SD ($F(2.05, 30{,}76) = 7.11$, $p < .01$, $\eta^2=.32$) and for ER ($F(2.09, 31.41) = 5.77$, $p < .01$, $\eta^2=.28$).

There was a significant interaction of the factors **VIEW*ANGLE** for the measure of RT ($F(2.92, 43{,}70) = 6.64$, $p < .01$, $\eta^2=.31$) which is visible in the intersect at 180° (see square in Figure 32). This effect did not reach significance neither for the measure of SD ($F(7,105) = 1.65$, $p = 130$) nor for ER ($F(2.54, 38.12) = 1.21$, $p = 347$).

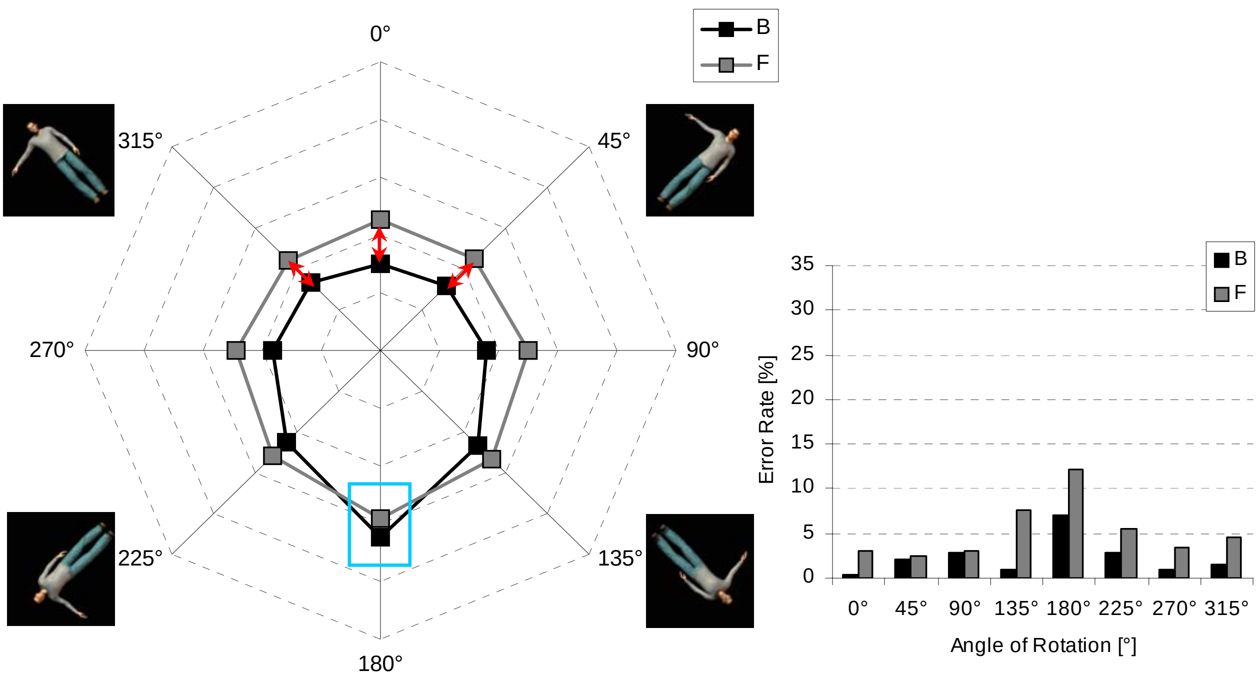

Figure 32 PICT PLANE: **LEFT**: RT (every layer equals 500ms), **RIGHT**: Error Rate

Table 3 shows the Bonferroni-corrected pairwise comparisons (of average RT) of different ANGLES of rotation which are interesting to compare with the following results for the depth plane condition when considering the "equivalent", or mirrored (left-right vs. front-back) respectively positions highlighted in table 3 and 4). The results show clearly symmetrical results for figures rotated to the left or right side with all of the mirrored comparisons (45°-315°, 90°-270° and 135°-225°) all being non-significant.

Table 3 Pairwise comparisons of different angles of Rotation for the PICT PLANE condition

	0°	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**
0°								
45°	n.s.							
90°	n.s.	n.s.						
135°	$p < .05$	n.s.	$p < .05$					
180°	$p < .05$	$p < .05$	$p < .01$	$p < .05$				
225°	$p < .05$	n.s.	$p < .05$	n.s.	$p < .01$			
270°	$p < .01$	n.s.	n.s	n.s.	$p < .05$	n.s.		
315°	n.s.	n.s.	n.s.	$p < .05$	$p < .05$	n.s.	$p < .05$	

DEPTH PLANE

A two-way analysis of variance (ANOVA) with repeated measures with the within factors VIEW and ANGLE of rotation revealed a significant effect of the factor **VIEW** for RT ($F(1,15) = 31.60$, $p < .001$, $\eta^2=.68$) for SD ($F(1,14) = 20.57$, $p < .001$, $\eta^2=.60$). This effect was not significant for ER ($F < 1$).

The main effect of the factor **ANGLE** of rotation was highly significant for the measure of RT ($F(2.22, 33.24) = 31.82$, $p < .001$, $\eta^2=.68$) and SD($F(2.81, 39.37) = 15.02$, $p < .001$, $\eta^2=.52$) and also for ER ($F(2.41, 36.11) = 16.00$, $p < .001$, $\eta^2=.52$). In contrary to figures rotated in the PICT plane, participants show a strong asymmetry with a peak at 225° angle of rotation in the DEPTH PLANE condition (see Figure 33).

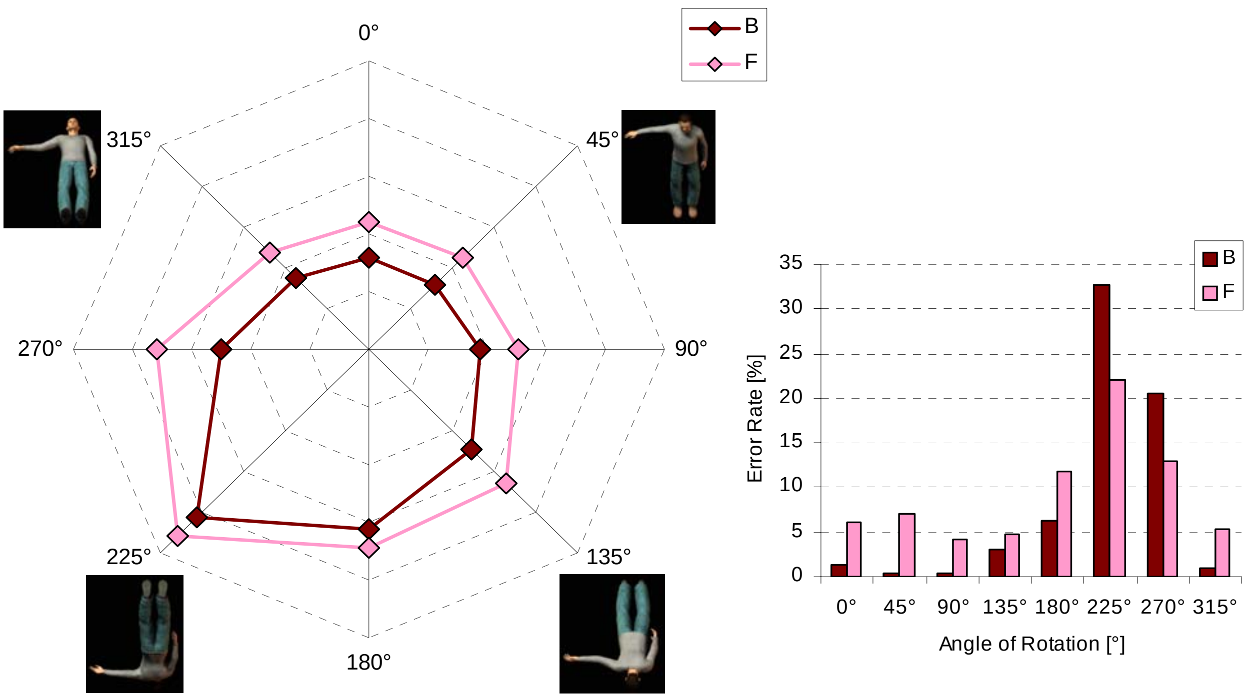

Figure 33 DEPTH PLANE: **LEFT**: RT (every layer equals 500ms), insets show the example of a FRONT VIEW figure with its right arm extended in the Angles of rotation 45°, 135°, 225° and 315°, **RIGHT**: Error Rate

In contrary to the condition PICT PLANE the interaction **VIEW*ANGLE** did not reach significance which is also clearly visible in Figure 33.

Table 4 shows the Bonferroni-corrected pairwise comparisons (of average RT) of different ANGLES of rotation. In contrary to the picture plane condition, pairwise comparisons reveal significant effects for the comparisons of 90°-270° and 135°-225°.

Table 4 Pairwise comparisons of different angles of Rotation for the DEPTH PLANE condition

	0°	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**
0°								
45°	n.s.							
90°	n.s.	$p < .05$						
135°	$p < .01$	$p < .01$	$p < .05$					
180°	$p < .01$	$p < .01$	$p < .01$	n.s.				
225°	$p < .001$	$p < .001$	$p < .001$	$p < .01$	n.s.			
270°	$p < .01$	$p < .001$	$p < .001$	n.s.	n.s.	$p < .01$		
315°	n.s.	n.s.	n.s.	$p < .05$	$p < .01$	$p < .001$	$p < .001$	

An interesting observation during analysis of DEPTH PLANE data was that contrary to all other cases where ER always lead to higher RT in general, rotation angle 225° was the only angle of rotation where time taken for erroneous response is lower than for the correct response. This finding could indicate a systematic error.

General Discussion

General Observations

A post-hoc analysis of front view figures only reveals a minor effect of ANGLE ($p < .05$) in the PICT PLANE condition. This is contrary to data reported by ZACKS ET AL. (2000) who did not find this effect for frontally presented body figures in what he referred to as an egocentric rotation task (left-right decision task). Furthermore, and also contrary to the findings by ZACKS ET AL. (2000), reaction times are generally smaller for the picture plane condition. It is noteworthy that ZACKS and colleagues did not test back view figures and it seems questionable if his conclusion of egocentric transformation (lacking the typical orientation effect) holds when the pronounced orientation effect for the back view figures is considered. Participants report applying both egocentric ("rotating myself into the figure's position") and more object-centered ("rotating the figure up to my position") strategies. Is it possible that they use more object-based transformations for stimuli that are rotated more than 90° away from the upright? Another hypothesis to consider is that figures facing the observer trigger different rotation strategies than back view figures.

Flipping Effect

Contrary to our expectations, the figures rotated in depth on average did not provoke mental flipping; reaction time patterns on average do not show that strategy and the corresponding angles of rotation (FR180° and BA180°) of both conditions show analogue reaction times. The presumed acceleration of the rotation in the DEPTH PLANE condition could not be confirmed (in none of the analyzed measures, RT, SD or ER). This should have been noticeable with strikingly lower reaction times (e.g. KANAMORI & YAGI, 2002; MURRAY, 1997). Even though this is not the case, some participants report using a flipping strategy and an individual analysis of RT-patterns actually reveal such patterns: In the depth plane, 7 participants showed a decreased RT at 180 (relative to the neighboring angles of rotation 135° and 225°) and out of these only two showed according behavior for the picture plane condition[20] (see Figure 34).

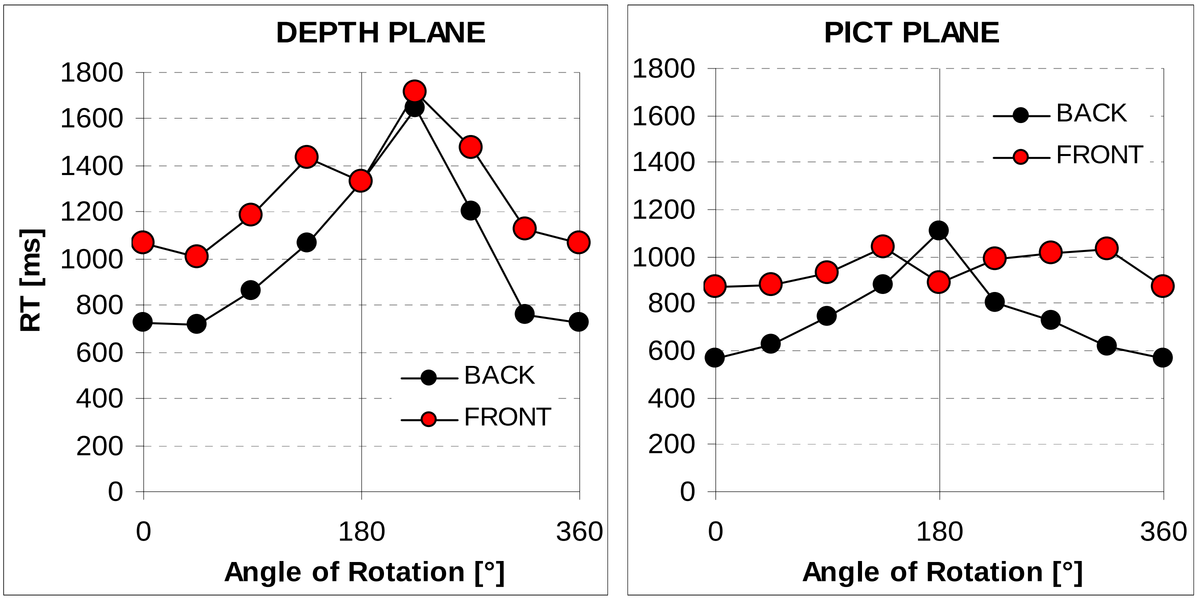

Figure 34 Flippers: **LEFT**: only seven out of 16 participants showed that they actually seemed to have flipped the front view figures at 180° up to the upright and showed decreased RT for the DEPTH PLANE condition. Out of these only two (**RIGHT**) showed the according behaviour in the PICT PLANE rotation.

This result complies with the hypothesis that the depth condition enables more subjects to flip the figure presented at 180°. It however seems as if the flipping strategy does not work as efficient for every one because more participants reported using the flipping strategy than could be confirmed with a clearly reduced reaction time. The effect seen here also implies that seeing (training) rotations in the depth plane can indeed evoke a more efficient strategy for some participants.

[20] One participant (#53) started with the depth plane condition, while the other (#25) started with the picture plane condition. Of the ones showing only flipping effects in the depth plane, 2 (#63 66) started with the depth plane, while the others (#57, 59, 62) started with the picture plane.

Effect of Plane; Asymmetry in the Depth Plane Rotation

The striking difference between the picture and depth plane indicates that different strategies seem to be involved. We do not merely rotate the presented figure to the upright position in a physical manner. Clear orientation effects are visible in both conditions. In the condition depth plane however, reaction times show a much larger range than in the picture plane. Furthermore, the RT function shows a strong asymmetry: the peak for reaction times is not at 180° as in the picture plane but at 225° (see Figure 33). This asymmetry of body figures rotated to the front or back in depth plane needs further consideration. Assuming that we rotate in our heads no matter in what direction, we could assume that "mirrored" rotation angles (deviation from the upright position) to the front or back should take the same amount of time but this is clearly not the case.

As discussed by PARSONS (1987A), orientations facing away (showing the top of body pointing away from the observer (315°. 270°) and below the horizontal plane away from the observer (225°) lead to higher reaction times. Also, the upright and "familiar" (canonical) position clearly seems to include all positions deviation no more than 45° no matter if to the left-right or back-front and effects show as soon as mental rotation exceeds 45° from the upright position.

Further explanation for the strong asymmetry of the angles of rotation 90°–270° and 135–225° in the DEPTH plane (former $p < .001$, latter $p < .01$) could be due to different factors:

- The *unusual perspective* of these figures: At 225° only the soles of the shoes are visible – a position that differs quite strongly from the canonical perspective of a human figure. It is very seldom that we come across a figure tilted 90° or more towards the back, and position 225° can not be imagined as a person "lying on the floor" because we never see a person in that position. The position 135° on the other hand is easier to interpret because it resembles a perspective of a lying person. People's mental representations of space seem to be derived from their typical experience in it.
- The *unnatural perspective* of 225°: Even when we imagine or simulate a person jumping or falling, 225° would be a view that never occurs because of gravitational reasons. The position could be part of a jump or a flip for example but the visible position itself will be of very short duration (transient orientation, CREEM ET AL., 2001B). These are rare actions that are transiently gravity-defying. The different speed (RT) could be interpreted analogue to adopting the according position in real life; it is easier and more intuitive to fall forward than imagine falling backward.
- Attention could be focused on the *visible face*. Could different processes/strategies be triggered when the face is visible or not? The face visibility could possibly trigger more egocentric processing.
- *Fewer parts (pixels)* are visible: According to CAVE and KOSSLYN (1993) it takes longer to recognize objects when fewer parts (geons) are visible. Studies investigating mental rotation of objects in the depth plane emphasize the influence of the view (KANAMORI & TAKEDA, 2003). Depending on the view, the visibility of an object is of major relevance for recognition.

These hypotheses are in line with mental rotation studies investigating pictures of body parts (hand or feet): the less natural the perspective of the stimulus, the longer it takes to make a decision. In experiments where participants are to judge physical or imagined body orientations they show higher reaction times and error rates the more these orientations deviate from an orthogonal (a representation of the body's vertical axis perpendicular to the array) observer-array relations (CREEM ET AL., 2001B; KOURTZI & SHIFFRAR, 1999).

Effect of "Face Visibility"

Once again it needs to be stressed that the designation of angles for rotations in the depth plane was applied starting towards the front. Yet, VIEW is not an entirely misleading term in the depth plane since it implies a un-/necessary rotation in the yaw-axis; front view figures, no matter if in the depth or picture plane always require a concurrent yaw rotation. Yet, to do justice to the term, a post-hoc analysis was conducted with regard to whether the face of the figure was visible or not to be able to better compare the two experimental conditions (see Figure 35). The data does not support the hypothesis that visibility of the face leads to a significantly different pattern of

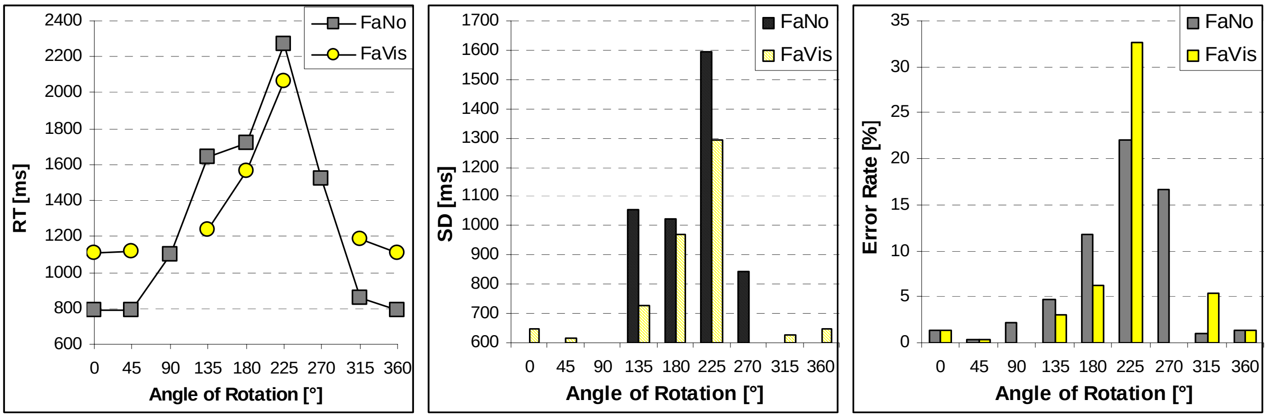

Figure 35 Face visibility shown for RT (LEFT), SD (MIDDLE) and ER (RIGHT): Positions 90 and 270 are grouped together and allocated to the group with face not visible (FaNo).

results yet positions where the face is visible on average lead to lower RT. It is noteworthy that the standard deviation is clearly higher for figures not showing their face compared to figures with their face visible. This could indicate that subjects differ in how well they "profit" from the face visibility by applying a more consistent strategy.

Congruency between Rating and Button Laterality

The effect that incongruent responses take longer (Simon effect) shows very well in the data acquired in the depth plane: back view figures rotated in the depth plane always require a congruent response (left arm is always on the left side of the visual field and right arm always to the right), while front view figures always require an incongruent response (button press opposite to visual field). This explains why the interaction of VIEW*ANGLE here does not reach significance in contrary to the data of the picture plane where congruence is dependent on angle of rotation.

The question remains as to how far the physically perceived body position influences left-right judgments in the depth plane. Depending on the body position of the observer, the relation towards the presented figure changes when this changes its angle of ration. Do we take into account gravitational cues of our own position for the interpretation of presented figures? Furthermore, does body position evoke different strategies specifically for the depth plane rotation? This issue will be further investigated in the following experiments POS-PICT and POS-DEPTH (page 23).

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3. Influence of Body Position (Direction of Gravity) on Mental Rotation of Body Figures

Abstract

Does one's body position interfere with the processing of body figures in a mental rotation task and is the direction of gravity integrated relative to the stimulus? EXP POS-PICT and POS-DEPTH investigate mental rotation of body figures in altered body position of participants (upright, supine, side and prone) to elucidate if the direction of gravity enables other processes and strategies in a left-right decision task. In EXP POS-PICT, a mental rotation left-right decision task containing body figures (line drawings) rotated in the picture plane is conducted by participants who themselves are placed in three different body positions. In EXP POS-PICT (EXP 1a) 13 participants are tested in the supine, upright and side position, in EXP POS-PICT (EXP 1b) data of 13 further participants are collected in the supine and upright position only. The same task is required for EXP POS-DEPTH; however two aspects of the stimuli used are different: rendered, more naturally looking stimuli of human figures are rotated in the depth plane. 24 participants took part in this experiment. Results demonstrate that only when positioned sideways, participants showed reaction times systematically different to the other two conditions (EXP 1a). This suggests that the side position evoked a slight displacement of maximal RT which could imply a shift of the applied reference frame. Obviously no benefit can be drawn from "aligning" the observer's body position to that of the presented figure. Analysis of individual data however suggests that some participants take advantage from aligned positions by showing decreased reaction times for figures presented at 180°, especially when presented figures are rotated in the depth plane.

Introduction

A wealth of knowledge of mental rotation tasks has been acquired. These paradigms vary in various aspects such as the kind of stimuli (human: e.g. PARSONS, 1987A / objects: e.g., SHEPARD & METZLER, 1971) used, the task parameters (left-right, right-wrong; PARSONS, 1987A; ZACKS ET AL., 1999; ZACKS ET AL., 2000; ZACKS ET AL., 2002; ZACKS, VETTEL & MICHELON, 2003), the kind of transformation (egocentric / object-based), manipulation of instructions (ZACKS & TVERSKY, 2005). The measurements taken are most commonly response times, error rates and introspective reports. A further measure to consider is standard deviation, offering a way to describe either how similar people solve a task or how consistent individuals solve various tasks in the experiment.

Previous studies have shown that visual representations of movements of the human body are influenced by restrictions of body movement paths and mental movements are integrated dynamically with other processes (e.g. KOURTZI & SHIFFRAR, 1999). Other studies have shown that mental transformation of the self as opposed to object transformation is generally easier (WRAGA ET AL., 2000), this however does not hold true for impossible self-rotations (CARPENTER & PROFFITT, 2001; CREEM ET AL. 2001B). Further studies have shown that postural information interacts with mental representations (SIRIGU & DUHAMEL, 2001). When hand position is misaligned with the to-be-imagined hand this leads to decreased performance unless the instruction is phrased from a third-person perspective. Other researchers also reported longer response times if the to-be-imagined position is misaligned with the participant's actual position (AMORIM & STUCCHI, 1997; CREEM ET AL.,

2001B, PARSONS, 1987A; PRESSON, 1982; PRESSON & MONTELLO, 1994, WANG & SIMONS, 1999; WRAGA ET AL. 2000; ZACKS ET AL., 2003). This has been interpreted as the use of analogue perspective transformations, which update the location and/or orientation of one's egocentric perspective. Information of vestibular receptors is essentially involved during coordination of body movements providing coordinates of the sense position and direction as neural codes in the proprioceptive system (OMAN, 2001). Astronauts report feeling upside down (sensation of inversion) when they move horizontally along the shuttle (KORNILOVA, 1997). They experience the phenomenon of suddenly feeling upside down and head movements are experienced as distressing and disorienting (LACKNER & DIZIO, 2000). Such visual reorientation illusions (VRI) result from the conflict when bodily sensations and gravity direction implied by the eyes are tried to be held in congruence (HOWARD, JENKIN & HU, 2000). These inversion illusions are difficult to reverse and continue when eyes are closed. Though VRIs usually occur spontaneously, they can be cognitively manipulated in much the same way one can reverse a figure/ground illusion or the perceived orientation of a Necker cube (OMAN, 2001).

Objects are recognized the fastest when they are presented upright (canonical view). The more the object differs from this canonical perspective, the more time is necessary for recognition (WASZAK, BREWING & MAUSFELD, 2005). Rotated, inverted objects need to be transformed to an upright position. But who defines what is upright? Is upright defined merely by the direction of gravity? Is the basis a subjective rating or is it dependent on an egocentric retinal frame of reference? And if, where does this put "upright"? The perceived gravitational vertical, although it may deviate from the objective vertical by some degrees (e.g., AUBERT, 1860; MITTELSTEADT, 1983), is most commonly used as a reference when the vertical has to be defined. Therefore, it has been argued that the earth's gravitational field is the dominant constraint for reference choice, at least when space is perceived (FRIEDERICI & LEVELT, 1990; ROCK, 1973).

The following experiment seeks answers to the question whether mental imagery processes are independent of the current sensory and perceptual inputs regarding the direction of gravity. There is increasing evidence for the assumption that mental activity influences perception and controlling of orientation (YARDLEY & HIGGINS, 1998). Some studies support the influence of gravitation on mental representations (CORBALLIS, ZBRODOFF & ROLDAN, 1976; CORBALLIS ET AL., 1978). The latter authors tested participants sitting upright and with their head tilted during mental rotation of alphanumerical digits. The authors suggest that the subjective frame of reference is more strongly linked to the gravitational frame of reference than to retinal coordinates. Other studies can not confirm an effect of body position on mental transformation but do so for recognition performance in composed images (e.g. MAST ET AL., 2003). When participants are asked to imagine an array of objects from another perspective they achieve better results with mental rotation of their own viewpoint than with that of the objects (WRAGA, CREEM & PROFFITT, 2000). The advantage with imagined rotation of the observer however only is initiated when rotation can be conducted parallel to the earth's surface (orthogonal) or perpendicular to the observer but not for other rotation axes (CARPENTER & PROFFITT, 2001). CREEM ET AL. (2001B) investigate if the cause lies within physical reality of gravitation (geometrical relationship between observer and environment). They showed that what matters is whether or not the axis of imagined rotation coincides with the body axis, not with gravity. Results show an advantage of mental self-rotation opposed to rotating objects in those conditions where there is a physical or imagined orthogonal relationship between observer and object. This leads to the conclusion that the advantage of egocentric rotation is based on the representation of the body-environment-relationship which is restricted by gravitation in the physical world. That is, egocentric rotation follows geometrical principles but these are affected by our experience with gravity (WASZAK, BREWING & MAUSFELD, 2005). Findings by CREEM ET AL. (2001B) also indicate that viewer rotation is easier than array rotation when the rotation is performed around one's principal axis, regardless of gravity.

In an upright position, the egocentric frame of reference is aligned with gravitational or allocentric frame of reference respectively. However, in a supine position these two frames of references are decoupled; the egocentric frame of reference is dependant on the person's body axis, while the gravitational frame adheres to the physical world, irrespective of head, body or eye movements (MAST ET AL., 2003). Can the altered direction of gravity with respect to the participants head position change performance for specific angles of rotation of the presented stimulus (positions orthogonal to body)? We hypothesize that an altered body position leads to altered performance. FRIEDERICI AND LEVELT (1990) tested two subjects during space flight and found that they are able to adequately assign positions in space (space-relative description of two objects) in the absence of gravitational information, and that they do this by using their head-retinal coordinates as primary references. Even though the subjects showed increased reaction times during space flight, this result indicates cognitive adaptation to the new situation: verticality can be assigned independently of perceived gravitation. The same authors tested subjects under a condition where gravitational information was present but irrelevant to the task being solved (subjects were in a horizontal supine position) and found that subjects are flexible in using cues other than gravitational ones as references when the latter can not serve as a referential systems. In this case participants base their response on head-retinal coordinates as a primary reference confirming that they are able to switch to a reference frame other than the one used normally when standing upright. An interesting finding is that when subjects conducted the task in the supine position with their head tilted, lower RT resulted than when the head was aligned with the body. This suggests that subjects do not gain facilitation from the fact that the head-retinal and the body-defined axes are aligned. The authors suggest that a higher computational load results when spatial assignment is required. Thus, even in a perceptually novel situation – as in space – information is mapped onto a representation that encodes verticality independent of the particular frame of reference provided by the apparent gravity (head-retinal frame of reference). FRIEDERICI AND LEVELT (1990) conclude that mental representation of space, onto which given perceptual information is mapped, is independent of a particular percept. This is also in line with an earlier space experiment finding that subjects are quite able to make spatial assignments in the absence of gravity; subjects in weightlessness were able to set a luminous line with great accuracy in the absence of gravity - at least when tactile cues were present (GRAYBIEL ET AL., 1967). They demonstrate that, in weightlessness, subjects predominantly use the head-retinal vertical as a reference frame, whereas on earth, the gravitationally defined vertical is used when possible. Subjects in an upright sitting or standing position were tested with their heads tilted. These studies had shown that although subjects sometimes used a reference frame that lay between the gravitational and the retinal coordinates, gravitational coordinates were dominant for the adult subjects' reference choices during perception of space or orientation in space (ATTNEAVE & OLSON, 1967; CORBALLIS ET AL., 1978). MATSAKIS AND LISPHIT (1993) also report that mental rotation is unimpaired during prolonged weightlessness and conclude that gravity is not an important environmental cue.

To our knowledge body position has not yet been examined systematically and previous research on mental body rotations was conducted with upright observers only. We believe that this could be of strong interest and relevance in relation to fMRI-studies where subjects are placed in a supine position and altered mental rotation processes may occur. In fact, some studies suggest that performance in some mental imagery tasks depends on the subject's body position respective to gravity (CORBALLIS ET AL., 1978; MAST ET AL., 2003). Also, when considering data of perceived body positions (JARCHOW, 2002) rotations in the Pitch-Plane (DEPTH rotation) are clearly different to rotations in the Roll-Plane (PICT plane rotation), on the one hand because of altered signals of the otoliths, but most probably also due to experience.

How does perceptual input and mental imagery processes depend on each other? Do we have gravity related rotation skills? "Where is upright"? Research on the subjectively perceived vertical has found a remarkable pattern of systematic errors at tilts beyond 60° (Aubert or A-Effect) as if body tilt is undercompensated or underestimated (BÖHMER & MAST, 1999). The Aubert-phenomenon corresponds to the effect that a vertical luminous line appears to be tilted towards the contralateral side (to the feet) when the participants lie sideways in a dark room. When participants are asked to adjust a luminous line to the subjective visual vertical (SVV) it is accordingly misaligned towards the head. The A-Effect (MÜLLER, 1916) indicates that the angle of the subjective visual vertical is smaller than the body tilt. This effect occurs when body roll-tilt is higher than 60-70° and reaches its maximum near 130° (VAN BEUZEKOM & VAN GISBERGEN, 2000). At smaller body tilts, the E-Effect describes the opposite effect when the line is adjusted towards the feet. The underlying mechanisms of this illusion are still being discussed, but the vestibular system (otolith organs and semicircular canals), neck muscle proprioception and other somatosensory input seem to be involved (JAGGI-SCHWARZ & HESS, 2003; PAVLOU ET AL., 2003; TROUSSELARD ET AL., 2003). The ocular torsion is often highly correlated to the SVV and therefore an influence of ocular torsion or the underlying mechanism could be responsible for part of the errors in SVV from veridical (BÖHMER & MAST, 1999; PAVLOU ET AL., 2003). In addition a cognitive component has to be considered since imagery of roll tilts is able to produce an E-effect (MERTZ & LEPECQ, 2001). In a study of VAN BEUZEKOM, MEDENDORP AND VAN GISBERGEN (2001) active tilt of the head did not reduce the error of the SVV but helped to estimate the tilt angle of the head. According to GLAUS (2003), who investigated mental transformation of "senseless syllables" in different body positions, it seems as if participants orientate themselves in a retinal frame of reference when they are positioned at 180° (head down) and have an "aubertic" frame of reference for smaller tilt angles. The orientation 135° is of high interest because here transition from one reference frame to the other is supposed to take place (KAPTEIN & VAN GISBERGEN, 2004) which leads to augmented confusion. Some participants also report that they have two different "up"-directions (one in the direction of their feet and the other towards their head). ATTNEAVE AND OLSON (1967) report a preference of the retinal frame when participants are pressed for time which could explain the choice of the retinal frame of reference at body position 180°. The difference in experience of the body positions could be a reason for switching between the two frames of reference.

How "egocentric" is egocentric rotation? Are there different rotation strategies involved and what is their advantage? We assume that perceived body position (body schema) alters space cognition and triggers different rotation strategies. This could be done by triggering an altered "egocentric perspective" with respect to gravity and which could lead to altered perception of an external human body figure and the way a person "empathizes" with it (embodiment). Mental transformation processes may depend on the sensation of spatial relations between the observer's body and the presented stimuli as well as of the relevant frame of reference of the observer. If the gravitational frame of reference is relevant for the rating of mental rotation angles then body position should change the perceived stimulus position systematically and also cause a change of cognitive demands. We suggest that mental rotation of figures (rotated in the picture plane for EXP POS-PICT (1a and 1b) or rotated in the depth plane for (EXP POS-DEPTH) is dependant on body position of the participants due to the direction of gravity implied in the stimuli and concurrent physical body position of the participant (direction of gravitational force with respect to position of the participants head). This could lead to accelerated responses favoring specific rotation angles of presented human figure (e.g. lower RT for 180°). We hypothesize that prone and supine positions are easier (less mistakes, shorter RT) for specific angles of rotation of stimuli (180°) by taking into account that imagining that the figure presented at 180° is "closer" to the participants own (supine/prone) position and should facilitate the decision by requiring "less to rotate". This should lead to lower RT and lower error rates at position 180° compared to upright position.

Experiment POS-PICT (1a & 1b): Picture Plane MR in Upright, Supine and Side Body Position

Method

Participants

Thirteen (7 female, on left-handed, mean age 28.8 years, range 24-35 years) healthy volunteers participated in the EXP 1a and 13 (5 female, one left-handed, mean age 32.7 years, range 19-40 years) in EXP 1b. All subjects had normal or corrected to normal vision and they were naïve with regard to the hypothesis under investigation.

Materials and Procedure

Drawings of human body figures are presented in eight different rotation angles (45° interval steps, clockwise, picture plane rotation) and in two different perspectives (front or back view). Each picture shows a human body with one arm (left or right) extended away from the body's midline and the other arm along the body's side (see Figure 36).

Each ANGLE of Rotation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), VIEW (front, back) and the number of left and right responses (left, right) appear equally often and the order of presentation is randomized in nine consequent blocks and balanced throughout the experiment (=288 judgments per condition, presented with SuperLab Pro 2.0 (Cedrus Corporation, 1999). Figures are presented on a flat screen (PC Intel Pentium III processor, 750 MHz, 256 MB RAM with a resolution of 1024 X 768 pixels), mounted in front of the subject's head. A cardboard tube is attached to the screen leaving the participants viewing only a circular view of the screen. Eye to monitor distance is kept at a constant 40 cm which leads to an angle of vision of 18.5 deg (Stimuli 13cm) and a chin rest ensures a stable position. The figures remain visible until the response is made and are followed by an inter-stimulus interval of 1000 ms.

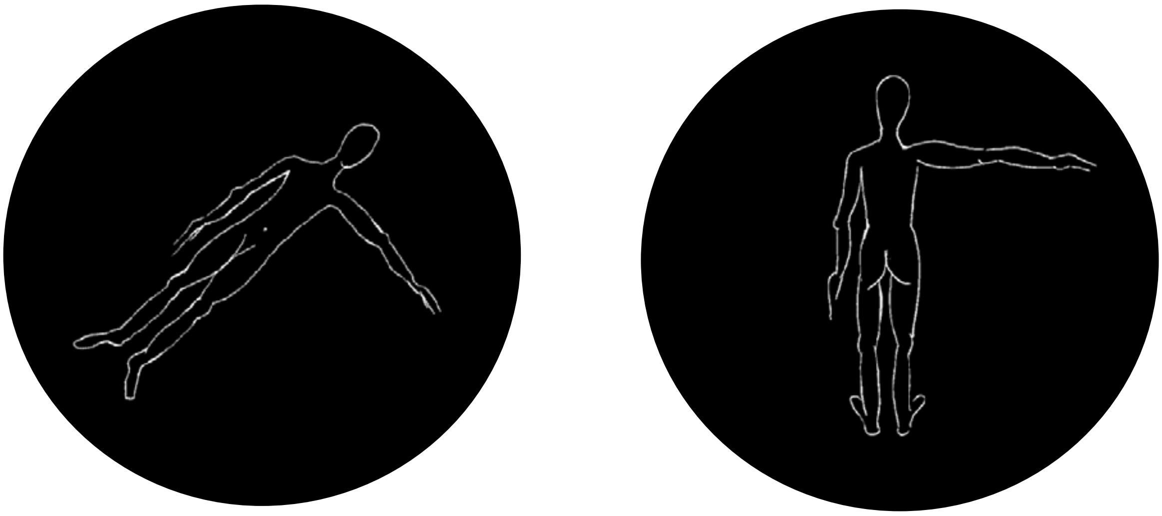

Figure 36 Line drawing figures used in the experiment POS-PICT, examples given show a front view figure at 45° and a back-view figure at 0°

A metal construction mounted on a tilt board placed the screen directly above (supine condition) or in front (side and upright position) of the participant's head (see Figure 37). The orientation of the screen was always relative to the person's vertical body axis.

Three experimental conditions are conducted and balanced throughout the experiment (within design): In a *supine* condition participants are asked to lie down on their back on the tilt board. In the *side* position (only in EXP 1a) participants are lying horizontally on their right body side and finally in the *upright* condition participants are seated and a head rest was used to ensure maintenance of a constant distance to the screen.

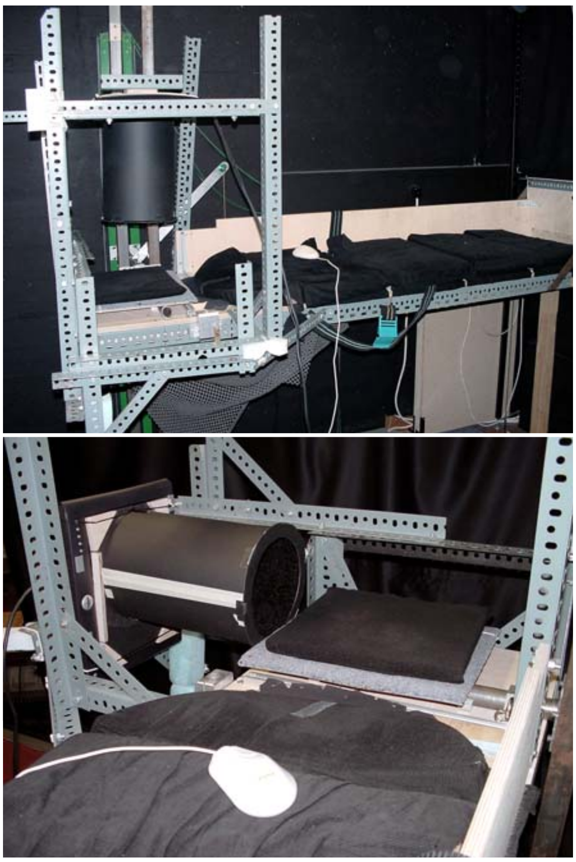

Figure 37: Experimental Setup for the different body positions: **LEFT**: UPRIGHT, **TOP RIGHT**: SUPINE, **BOTTOM RIGHT**: SIDE

Task. The participants have to decide which arm of the figure is extended away from the body's midline (left-right discrimination). They press a button of a serial mouse with their left thumb if they think the figure's left arm is extended and they press with their right thumb if they think the figure's right arm is extended. All participants are made familiar with the task prior to the experiment by completing a short practice trial before the main experiment begins (before each condition). They do not receive feedback regarding accuracy. For the following test trials they are repeatedly encouraged to decide as quickly as possible while remaining as accurate as possible. The serial mouse is placed in both of their hands with their arms resting on the table. The experiment takes about 45min (EXP 1a) or 30min (EXP 1b).

The independent variables of the stimuli are **SIDE** (left/right), **VIEW** (front/back) and **ANGLE** of rotation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°). Body Position (supine, upright, side) and **ORDER** ($1^{st}/2^{nd}$) are balanced throughout the experiment. The dependant variables are Reaction Time (RT, measured by the participant's click on the according key of a serial mouse), Standard Deviation (SD) and Error Rates (ER).

In a follow-up EXP 1b further participants were assessed in the conditions *supine* and *upright* position only (starting position counterbalanced). Procedure was identical to 1a.

Results and Discussion POS-PICT (a and b)

Data exclusion criteria:

- RT over 3s are excluded from data analysis (0.14% excluded in EXP 1a, 0.10% in EXP 1b).
- For RT analysis only correct responses are taken into account. Error rates are generally low: on average these are 3.1% in EXP 1a and 6.1% in EXP 1b.
- F-values from ANOVAs lower than 1 ($F < 1$) were not interpreted because the variability within the conditions was higher than between conditions. A Greenhouse-Geisser correction was applied when Mauchly's W reached a significance level of $p < .05$.

Introspective Reports

Participants report a strong advantage for back view figures and say that they based their decision on spatial judgments relative to themselves (first-person perspective) and not to an other person's perspective (third-person perspective) without being given instruction to do so. They underline this statement by imagining choosing "the same arm as mine" and therefore acting in an egocentric frame of reference.

Some of the participants report that they mentally flipped figures at the inverted position (180°) to the upright position, or their own body from upright to the 180° stimuli position (vs. rotating the figure 180° in the picture plane). They report preferences of body positions, however no systematic preference is noticeable and order of experimental sessions seems more relevant (the last session usually being described as the easiest).

One subject mentioned experiencing "congruency effects" in the side position where she mentioned (#36, EXP POS-PICT); "when the left arm was extended but showing downwards I always (mistakenly) pressed the right button". Another participant (#50) reported not mentally rotating at all.

Effect of POS (Body Position)

A three-way analysis of variance (ANOVA) with repeated measures with the within factors POS, VIEW and ANGLE was conducted and lead to the following results:

The participants' body position with respect to gravity did not affect task performance. The results show no significant effect of the factor **POS** neither regarding average RT, nor SD, (all $F < 1$). However, there is a significant effect of POS regarding ER: $F(2, 24) = 5.06$, $p < .05$, $\eta^2=.30$.

Results from the follow-up EXP 1b confirm that the supine body position per se does not alter task performance regarding RT and ER (both $F < 1$). Participants seem to be able to abstract from their present body position and rely on head-retinal coordinates.

However, Body position did interact with the other variables:

Error Rates showed a significant interaction of the factors **POS*VIEW** $F(2, 24) = 6.35$, $p < .01$, $\eta^2=.35$. There are no significant interaction effects in EXP 1b (all $F < 1$) except for ER analysis shows a slight, however non-significant interaction effect of POS*ANGLE ($F(2.66, 31.90) = 2.20$, $p = .114$).

There was a significant interaction of the factors **POS*ANGLE**: $F(14, 168) = 3.77$, $p < .001$, $\eta^2=.24$ for average RT and $F(14, 168) = 2.40$, $p < .01$, $\eta^2=.17$ for SD. A post-hoc analysis showed that this was due to the **SIDE** position (see circle in Figure 38).

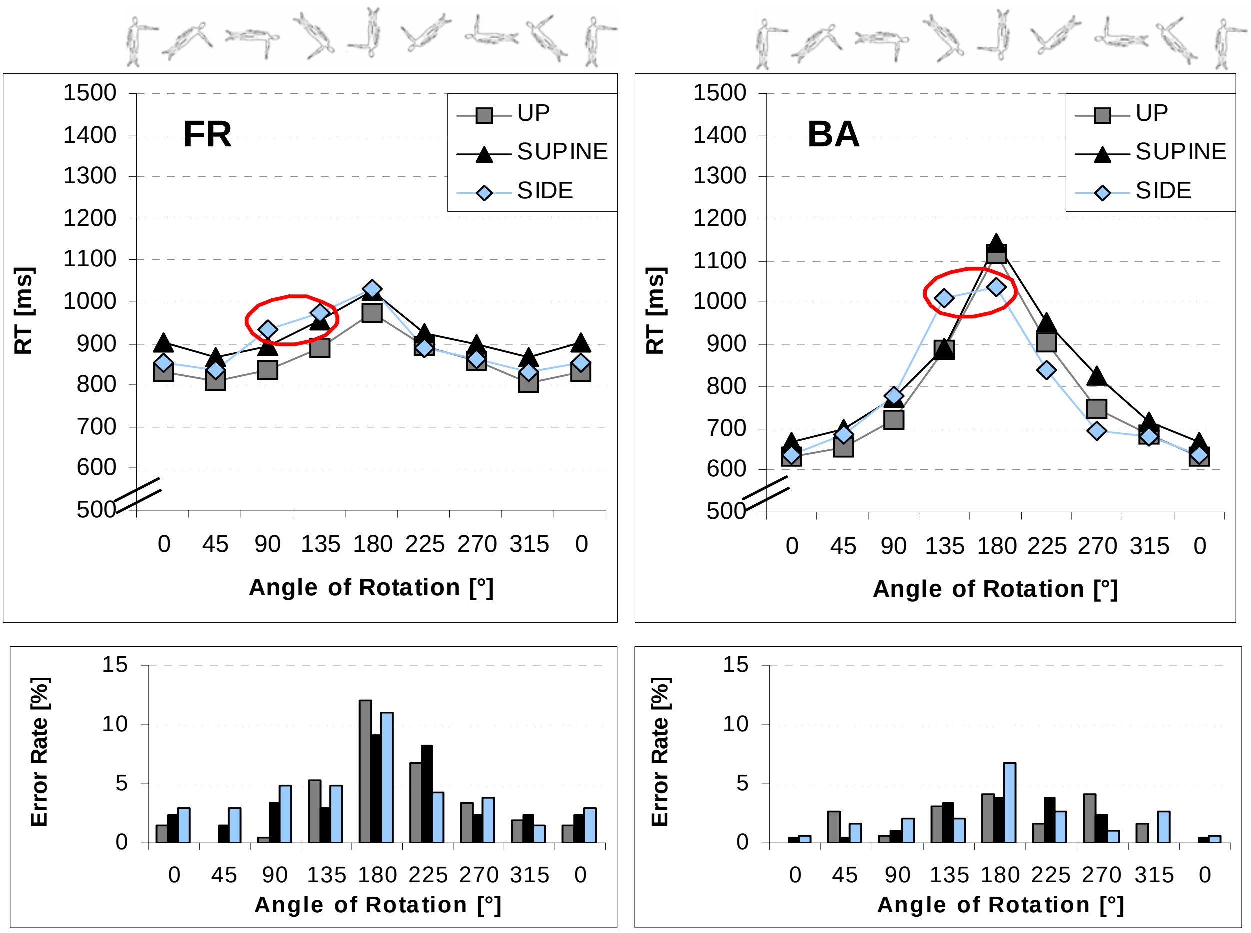

Figure 38 EXP 1a: Comparison of the upright (UP) supine (SUPINE) and sideways (SIDE) position; **LEFT:** front view figures (FR), **RIGHT:** back-view figures (BA). TOP: RT, BOTTOM: ER (N=13)

This significant interaction is also visible in the slightly displaced curve for the side condition. An 'A-Effect' (AUBERT, 1860, MÜLLER 1916) would not directly imply such a result. However, the question of "where is upright" is highly relevant here and most probably responsible for the effect of the side position. If we set the A-effect in relation to the participants' position and a figure at rotation angle 135° (in space coordinates this would be stimulus presented at 225°; stimulus presentation and coordinates are always relative to the participant's axis) should be shifted towards the 180° figure. If the figure were a visual vertical line at 45° angle of rotation in allocentric angles (feet of stimulus) we should expect that it is perceived closer to 180° (respectively 0° with its feet). If we assume that participants always rotate to their own position this would mean that RT would be longer for 135° and shorter for 180° as seen in this data. It is important to stress that a finer grid of various angles of rotation would be necessary to make precise and reliable statements in this matter.

Effect of ANGLE of Rotation

There was a clear effect of **ANGLE** reflected in increased average RT with $F(1.75, 20.95) = 44.80$, $p < .001$, $\eta^2=.80$, increased SD with $F(3.34, 40.02) = 18.83$, $p < .001$, $\eta^2=.61$, and increased ER with $F(3.34, 40.06) = 12.17$, $p < .001$, $\eta^2=.50$ toward to inverted figure at rotation angle 180°. (EXP 1b: RT: $p < .001$ and ER: $p = .053$). This is contrary to findings by ZACKS (2002) who also applied a left-right decision task with human sketches and did not find an orientation effect for this egocentric task with front view figures.

Bonferroni-corrected pairwise comparisons (of average RT) revealed the following (see Table 5)

Table 5 Pairwise comparisons of different angles of Rotation

	0°	45°	90°	135°	180°	225°	270°	315°
0°								
45°	n.s.							
90°	$p < .05$	$p < .01$						
135°	$p < .001$	$p < .001$	$p < .001$					
180°	$p < .001$	$p < .001$	$p < .01$	n.s.				
225°	$p < .001$	$p < .001$	$p < .01$	n.s.	$p < .01$			
270°	$p < .05$	$p < .05$	n.s.	$p < .001$	$p < .001$	$p < .001$		
315°	n.s.	n.s.	$p < .05$	$p < .001$	$p < .001$	$p < .001$	$p < .01$	

Effect of VIEW

A significant effect of **VIEW** (RT $F(1,12) = 12.94$, $p < .01$, $\eta^2=.52$. SD: $F(1,12) = 16.41$, $p < .01$, $\eta^2=.58$ and ER: $F(1,12) = 6.17$, $p < .05$, $\eta^2=.34$) leads to the assumption that different processes of mental rotation are involved. I suggest that the difference between front and back view figures is due to the additional yaw rotation at 0° (EXP 1b: $p < .001$ for RT and $p < .05$ for ER). Depending on the view of the figure (front or back view) there seem to be different mental processes at play. Front view figures show a general increased level and quite flattened pattern of reaction times except for the inverted angle of rotation (180°). At the same time error rates seem are higher for front view figures at this position showing that the increased speed for larger angular disparities does not lead to more accurate performance (speed-accuracy tradeoff). Participants make significantly more mistakes with front view figures (4.1% for front view and 2.1% for back view figures). The collected data show that front view figures generally lead to a higher level of response times and effect of rotation is visible especially for the orientations 135°, 180° and 225°.

The two-way interaction between **VIEW*ANGLE** was also significant with $F(2.61, 31.35) = 18.31$, $p < .001$, $\eta^2=.60$ for RT, with $F(7, 84) = 3.13$, $p < .01$, $\eta^2=.21$ for SD, and not reaching significance for ER with $F(7, 84) = 1.71$, $p = 119$, $\eta^2=.12$. (This effect did not show in EXP 1b: RT: $F(1.45, 17.42) = 6.11$, $p = .015$ and ER: $F < 1$). The significant interaction effect in 1a might imply a change of strategy (large (>90°) versus small (<90°) angles of rotation).

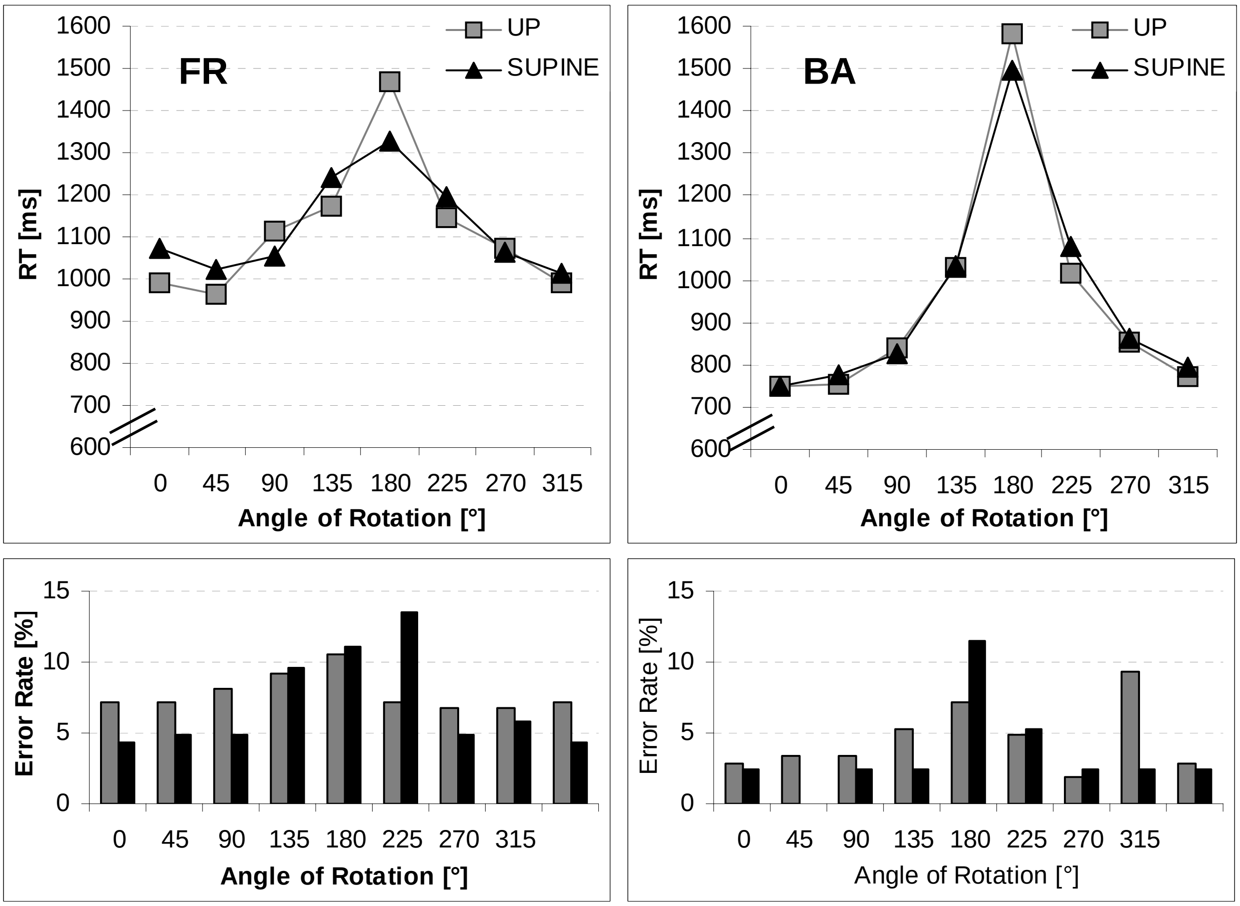

Figure 39 EXP 1b: comparison of the upright (UP) and supine (SUPINE) body position; **LEFT:** front view figures (FR), **RIGHT:** back-view figures (BA): **TOP:** RT **BOTTOM:** ER (N=13)

Follow-up Experiment 1b

Analysis of the 13 participants who only conducted the conditions upright and supine lead to similar results as found in EXP 1a. There seems to be a trend towards an advantage (lower RT) at stimulus position 180° when participants were in a supine as opposed to the upright position (see Figure 39). However, this effect was not significant.

Individual analysis: Flippers and Non-Rotators

Some authors (ZACKS ET AL., 2002; ZACKS, VETTEL & MICHELON, 2003) suggest that different cortical mechanisms are at work depending on the view of the stimulus. It is suggested that transformations requiring a pure plane rotation are associated with activation in the left posterior parietal cortex whereas front view stimuli are associated with activation in the right posterior parietal cortex. The different activations cannot be attributed to a difference in task difficulty because the ratings did not differ for front and back view stimuli. A closer investigation of flipping strategies (MURRAY, 1997) requires visual inspection of the individual data. It turned out that only one person showed what appears to be a flipping mechanism at 180° in the supine position (#2) in EXP 1a with shorter RT of the back view figure 180° relative to the neighboring 135° and 225°. In the follow-up EXP 1b, three participants showed this behavior. Interestingly, the flip-effect was again restricted to the supine position but here showed for the front view figure which is in line with what I expected; a "flipped" front view figure results in a back view figure (see left side of Figure 40).

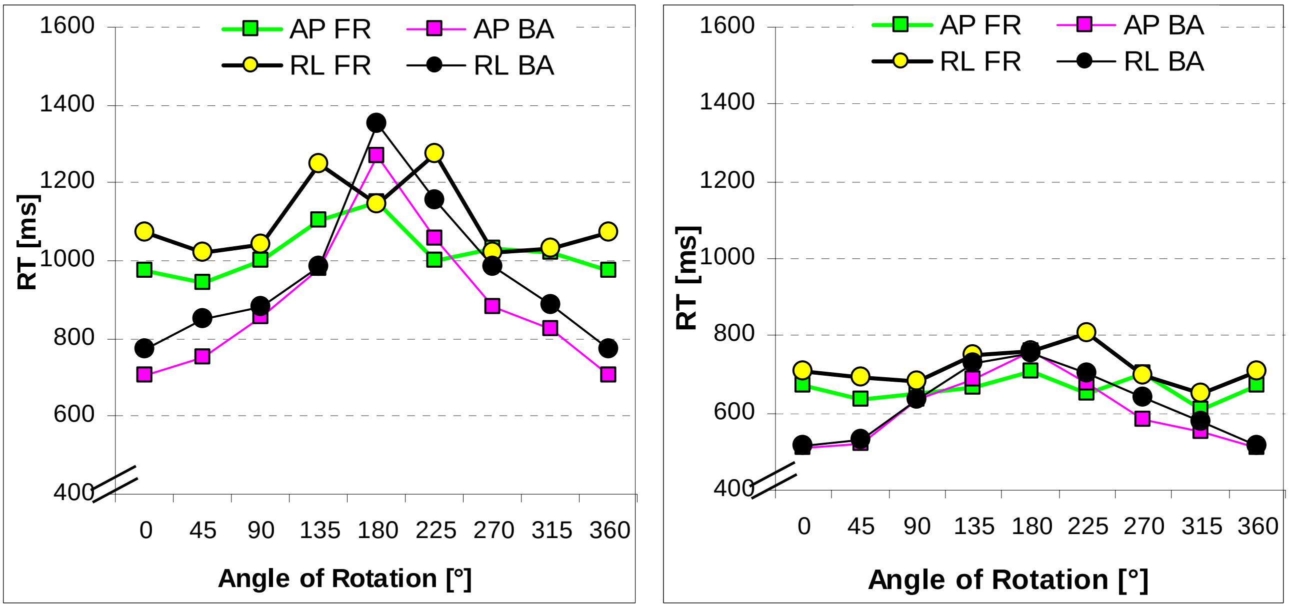

Figure 40 Flippers (participants #44, 45, 46) and a "non-rotator" participant (#50)

Inspection of individual data furthermore revealed that the participant reporting not mentally rotating at all indeed goes quite well with that report (see right side of Figure 40).

Effect of Training/Experience/Trial Order

A Paired Samples t-Test (2-tailed) with the factor **ORDER** revealed that participants show significant improvement (decreased RT) in the course of the experiment with $t(12) = 3.29$, $p < .01$ for the comparison 1-2, $t(12) = 3.47$, $p < .01$ for the comparison 1-3 and finally $t(12) = 2.62$, $p < .05$ (see Figure 41) for the comparison 2-3. This does not hold true for the error rate which stays more or less the same in the course of the experiment. Thus, people speed up but are not more accurate with their judgments.

A further analysis to investigate if this training effect was also noticeable within the experiment (comparison of the first four and last four blocks) revealed no significant effect. The improvement therefore is limited to consequent conditions and can not be verified for the course of the ongoing session. Participants also gave significantly faster responses with their right hand as is revealed by a Paired Samples t-Test (2-tailed): $t(12) = 2.66$, $p < .05$.

The following experiment aims at intriguing more participants to show reduced reaction times for the 180° figure orientation by positioning them "in line" with the flipping mechanism (prone and supine position) and moving them psychologically and physically closer to that position.

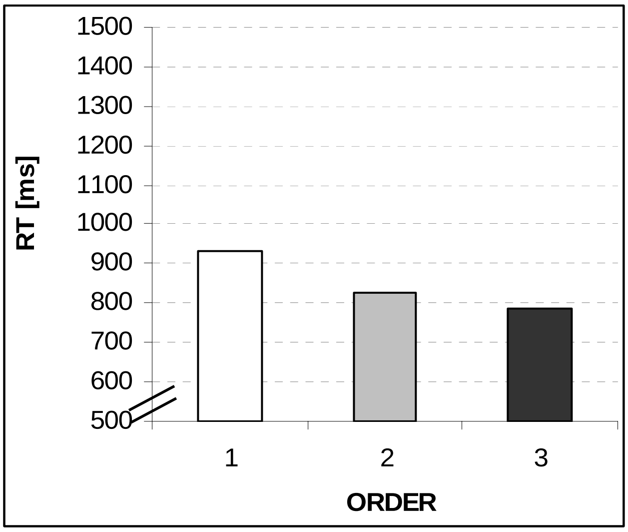

Figure 41 RT decrease in the course of the experiment is significant

Experiment POS-DEPTH: Depth Plane MR in Upright, Supine and Prone Body Position

Method

Participants

Twenty-four healthy volunteers (12 female, mean age 27.6 years, range 16-38 years) participated in the experiment. Three (2 female) were left-handed. All subjects had normal or corrected to normal vision and they were naïve with regard to the hypothesis under investigation. Seven subjects (#10, 11, 14, 26, 40, 48 and 57) had previously participated in another mental rotation experiment.

Material and Procedure

Naturalistic human body figures (created by a 3D figure design program, Poser 6) are presented in eight different rotation angles about the y-axis in the DEPTH plane (45° interval steps coded to the front) and in two different perspectives (front or back view). Each picture shows a human body with one arm (left or right) extended away from the body's midline and the other arm along the body's side (see Figure 42).

Figure 42 Human Body Figures, rotation in the DEPTH PLANE (example given is a back-view figure at rotation angles 0°, 45°, 90°, 135°)

Each ANGLE of Rotation (0°. 45°, 90°, 135°, 180°, 225°, 270°, 315°), VIEW (front, back) and the number of left and right responses (left, right) appear equally often and the order of presentation is randomized in nine consequent blocks and balanced throughout the experiment (=288 judgments per condition, presented with SuperLab Pro 2.0 (Cedrus Corporation, 1999). Figures are presented on a flat screen (PC Intel Pentium III processor, 750 MHz, 256 MB RAM with a resolution of 1024 X 768 pixels), mounted in front of the subject's head. A cardboard tube is attached to the screen leaving the participants viewing only a circular view of the screen. Eye to monitor distance is kept at a constant 40 cm which leads to an angle of vision of 15.7 deg (stimuli size 11cm at 0°) and a chin rest ensures a stable position. The figures remain visible until the response is given and are followed by an inter-stimulus interval of 1000 ms. A metal construction mounted on the tilt board places the screen directly above (supine condition), in front (upright position) or underneath (prone position) the participant's head (Figure 37) (always mounted relative to the persons' body axis).

Three experimental conditions are conducted and balanced throughout the experiment (within design): In a *supine* condition participants are asked to lie down on their back on the tilt board as in EXP 1a and 1b. In the *prone* position participants are lying on their stomach looking at the screen through an opening of the Tiltboard. Finally, in the *upright* condition participants are again seated and a head rest is used to ensure maintenance of a constant distance to the screen.

Task. Equal to EXP 1a and 2b. In addition to the experimental task, participants are asked to fill out a questionnaire consisting of difficulty ratings (1 (very easy) to 8 (very difficult)) of all figures in all possible rotation angles in the depth plane after the experimental session (see Appendix 2: DEPTH PLANE Questionnaire).

The experiment takes about 45min.

Results and Discussion Experiment POS-DEPTH

Data exclusion criteria:

- Since difficulty level was much higher in EXP POS-DEPTH and I wanted to set the criteria at a comparable level to EXP 1a and 1b the cut-off criteria of 9s leading to an exclusion of .17%.
- For RT analysis only correct responses are taken into account. Error rates are higher than in EXP 1a and 1b but still relatively low, with an average of 5.6%.
- F-values from ANOVAs lower than 1 ($F < 1$) are not interpreted because the variability within the conditions was higher than between conditions. A Greenhouse-Geisser correction was applied when Mauchly's W reached a significance level of $p < .05$.

Introspective Report

One person (participant #70) reported taking over the perspective of the stimulus but also said that he had a lot more trouble with this when the figure was not facing him (face not visible). He is not the only person (#78) reporting that "is the figure looking at me triggers if I myself rotate into the figure's perspective or on the other hand rotate the figure up to me". One person only reported taking over the figure's perspective in the prone position while she solves the other tasks in an object-based transformation manner (#40). Errors were often reported to be a "motor problem" because all of the participants reported "knowing" right away when they pressed the wrong button.

Effect of POS (Body Position)

It has to be considered that coding of rotation angles was arbitrary and not directly comparable between conditions PICT and DEPTH condition. In the PICT condition angles were coded clockwise, while for the DEPTH condition increasing angles were starting towards the front.

As in EXP 1a and 1b, the results show no significant effect of the factor **POS** regarding average RT and SD of RT and here also no significant effect in the ER analysis (all $F < 1$).

The three-way analysis of variance (ANOVA) with repeated measures performed on the data with the factors POS, VIEW and ANGLE yielded no significant main effects regarding RT and SD, however an analysis of ER revealed a significant interaction effect for **POS*VIEW** with $F(2,46) = 5.85$, $p < .01, \eta^2=.20$.

Effect of ANGLE of Rotation

There was a strong effect of **ANGLE** of rotation reflected in the increased average RT with $F(1.94, 42.59) = 46.39$, $p < .001$, $\eta^2=.68$, an increased SD with $F(2.06, 47.30) = 48.19$, $p < .001$, $\eta^2=.68$, and a significant general increase of ER with $F(1.80, 41,45) = 17.76$, $p < .001$, $\eta^2=.44$ toward the position of the inverted figure at 180°.

Table 6 shows the Bonferroni-corrected pairwise comparisons (of average RT) of different ANGLES of rotation.

Table 6 Pairwise comparisons of different angles of Rotation for the DEPTH plane condition

	0°	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**
0°								
45°	n.s.							
90°	$p < .05$	$p < .05$						
135°	$p < .001$	$p < .001$	$p < .001$					
180°	$p < .001$	$p < .001$	$p < .001$	$p < .05$				
225°	$p < .001$	$p < .001$	$p < .001$	$p < .001$	$p < .001$			
270°	$p < .001$	$p < .001$	$p < .001$	n.s.	n.s.	$p < .01$		
315°	$p < .001$	$p < .001$	n.s.	$p < .01$	$p < .001$	$p < .001$	$p < .001$	

Effect of POS

There is no significant effect of body position reflected in the responses. Separate comparisons of the conditions (upright-supine, upright-prone, supine prone) did not show significant differences either. Reaction time functions are quasi-parallel and show the same kind of asymmetry as in EXP PLANE. In the supine condition responses for figures at 270° are slightly lower, especially with face-up (rotation angle 270°, see Figure 43). The opposite is true for the prone position, where face-up as well as face down reaction times are augmented at 270°. A possible explanation is that

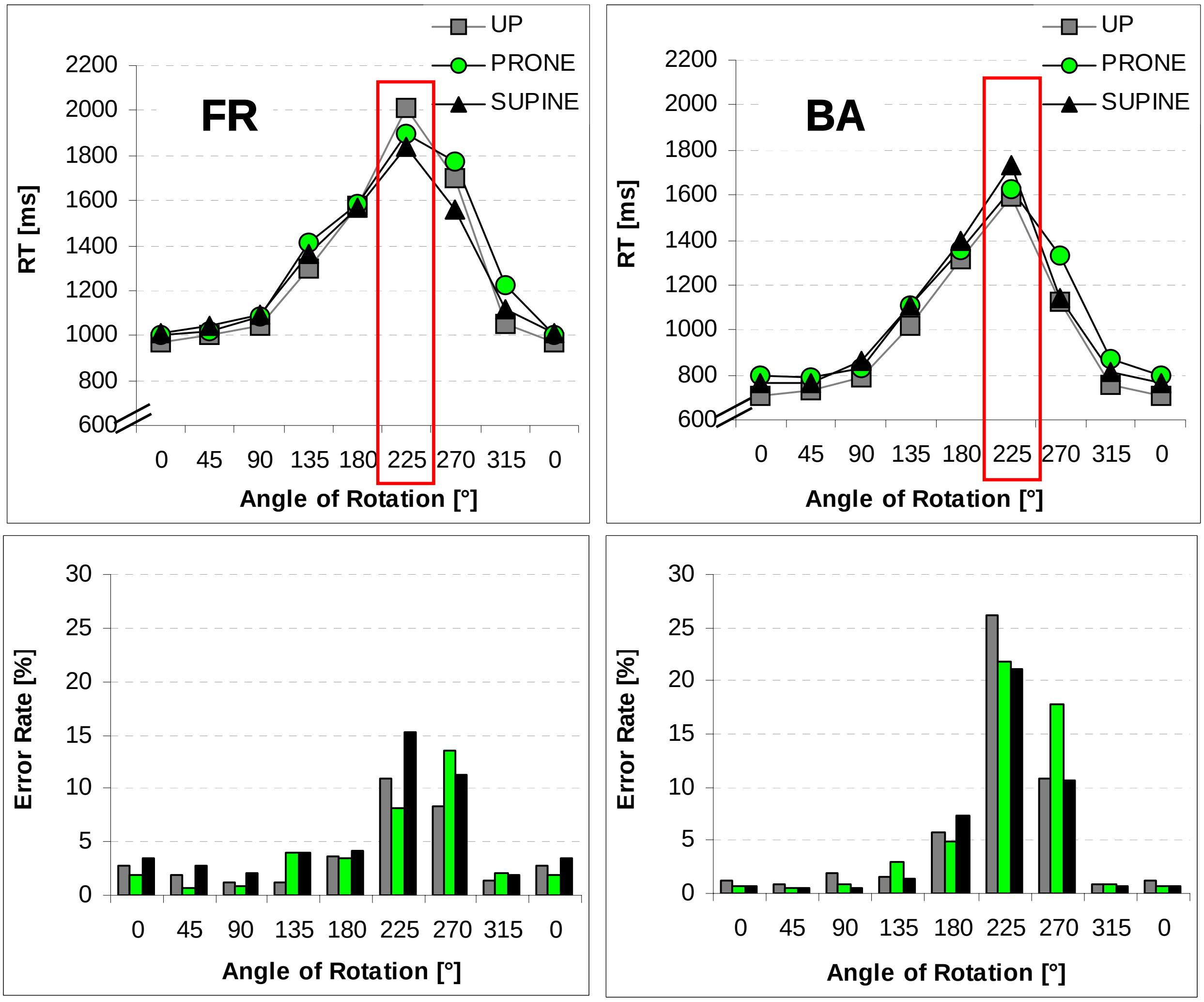

Figure 43 EXP2: comparison of the upright (UP), prone (PRONE) and supine (SUPINE) position; **LEFT:** front view figures, **RIGHT:** back-view figures. **TOP:** RT, **BOTTOM:** ER (N=24)

the tiltboard corresponds to a physical obstacle for a 180° self-rotation about the vertical axis specifically affecting this stimulus orientation.

Individual analysis regarding flipping-mechanisms revealed that 16 out of 24 participants did indeed show decreased RT relative to neighboring orientation positions; this was mostly the case for the angle of rotation 180° (i.e. 135°>180°<225°) but also showed for 225° (i.e. 180°>225°<270°). The following Table 7 summarizes the percentage of those participants obviously applying and taking advantage of this more efficient strategy for the according 16 participants. Inspection of the data shows that flipping seems to work better for the front view figure. Consideration of error rates reveals that the strategy indeed seems to work well; only in three cases participants show increased error rates relative to the according position. This is furthermore only the case for the angle of orientation 225° and only for the back view orientation.

Table 7: Percentage of flipping strategies shown in for the 16 participants who did show the flipping strategy in any of the conditions or views for EXP POS-DEPTH.

	180°		225°	
	FRONT	**BACK**	**FRONT**	**BACK**
UP	18.8%	18.8%	-	12.5%(all with inferior ER)
PRONE	31.3%	18.8%	-	12.5% (half with inferior ER)
SUPINE	25.0%	12.5%	6.3%	12.5%(half with inferior ER)

Analysis of Questionnaire

The questionnaire was unfortunately only completed by 14 of the 24 participants because it was only constructed after some participants had already taken part in the experiment. The analy-

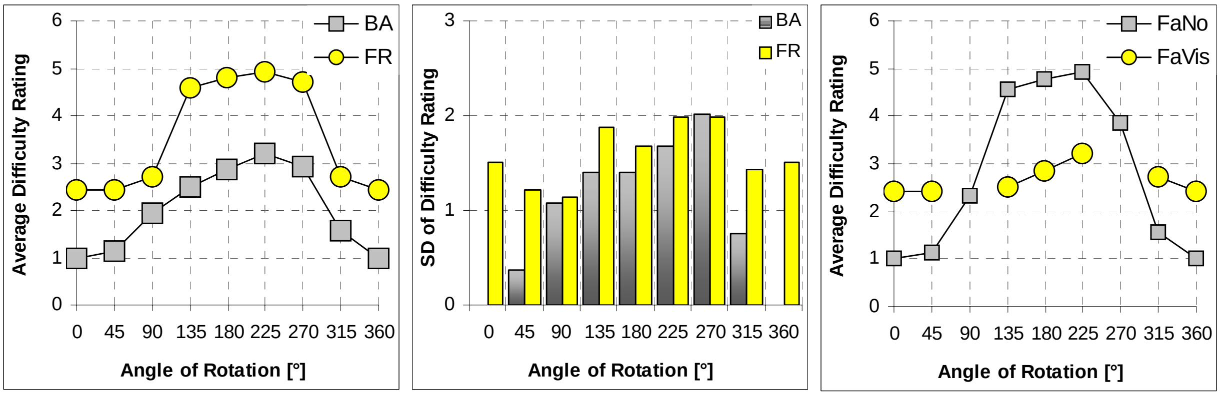

Figure 44 Paper-pencil difficulty ratings for all of the rotation angles for all front and back figures (min: 1, max: 8) **LEFT:** average difficulty rating shown separately for front and back-view figures (view defined by upright figure); **MIDDLE:** standard deviation for the same and **RIGHT:** average difficulty rating shown for figures with visible face (FaVis) or for figures where the figure's face is not visible (FaNo) (N=14)

sis reveals that the behavioral data fits quite well to the data gathered in the difficulty rating by the participants (see Figure 44). Participants consistently consider the task to rate back view figures easier than front view figures[21], independent from angular disparities from the upright position. The experimental situation where parallel matching is most efficient for the back view figures is also quite well visible in the questionnaire data. Also, the asymmetry is somewhat visible, more so for the back view than the front view figures. Many participants reported "flipping" the figure to the upright and then matching it, this strategy would clearly favor the front view figure at 180° because it ends up being the 0° seen from the back. However, based on the questionnaire data there is no hint that participants consider "flipping" an adequate strategy at the 180° angle of rotation. Participants reported that they consider 90° angle of rotation a lot easier than 270° (which is also visible in the questionnaire data, see Figure 44). When ignoring the original back and front view assignments and only taking in account the "face visibility" the data shows a flatter course of difficulty ratings for figures with face visible as compared to a strong orientation effect for those figures with no visible face (see Figure 44, graph on the RIGHT). Correlations of questionnaire data and average reaction times (for upright position only and for 14 participants only) with respect to angular disparities are between .68-.90 for all but two participants (r=.43, .45; also see average correlation in Figure 45). This shows that participants are well able to estimate their performance or else use the same strategies when theoretically estimating the difficulty and actually conducting the mental rotation task. When correlating error rates with difficulty estimation there is no clear trend; correlations range from -.18 to .71.

[21] Consider that "view" is defined from the starting position of the figure; this means that a front view figure is equal to a back-view figure at 180.

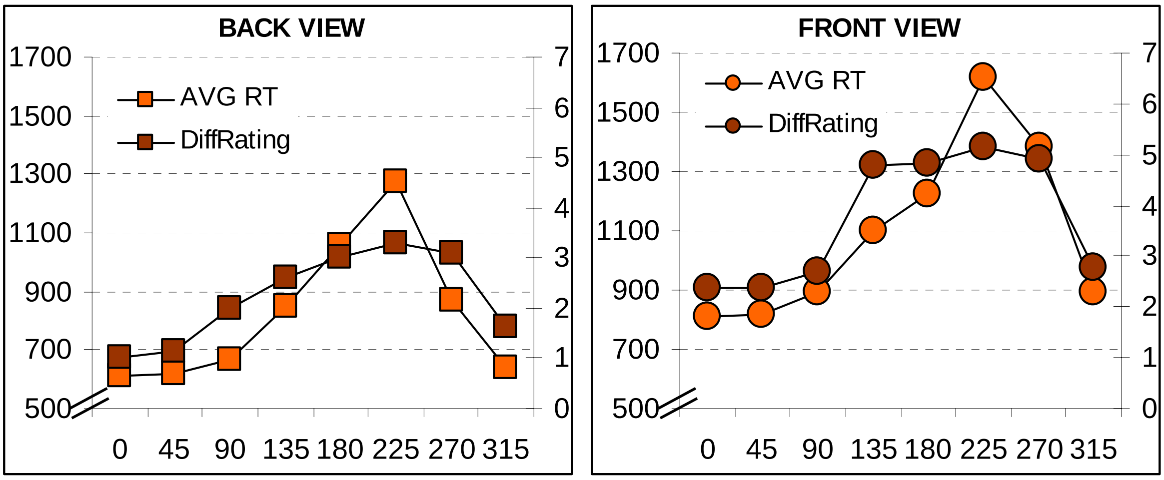

Figure 45 Average correlation of behavioral and questionnaire data for back-view figures (**LEFT**) and front view figures (**RIGHT**) (N=14)

General Discussion

The aim of this study was to investigate potential influence of body position on the way people process human figures presented in the same/different position relative to the observer (vs. space). Furthermore, EXP POS-DEPTH aimed at triggering an increased number of "flippers" compared to EXP POS-PICT.

In sum, the results of this study suggest that with exception of the side position, participants are able to abstract from their own position and nevertheless perform a kind of "egocentric" transformation; however this is entirely dependent on retinal input and not to the "egocentric" body as a whole.

Both experiments show a pronounced effect of orientation: Different views of the stimuli (with the inherent additional YAW-rotation for FRONT figure matching) lead to different patterns of RT relative to rotation angles. As mentioned, this might reflect a change of strategy, favoring front view figures when presented upside down (possibly implying a flip-effect) for figures rotated in the picture plane.

In contrary to the findings of ZACKS ET AL. (2002), reaction times are perspicuously shorter in my experiment and the data indicate a clear effect of orientation. Also in contrast to the data of ZACKS ET AL. (2002) I found a rotation effect for frontal stimuli as well as those shown from the back. He characterized the left-right task as an egocentric perspective transformation which is called into question with the present results.

Effect of Dexterity or Congruency?

There was a general effect of SIDE (left- vs. right arm extended) in all of these experiments (POS-PICT (a & b) and POS-DEPTH) with right-arm responses being on average 4% faster compared to left-side responses. This could be due to the majority of participants being right-handed (4 out of 50 left-handed). This SIDE-effect however is not categorically a result of handedness; PARSONS (1987A) compared vocal and manual left-right judgments and found the same strong effect which shows that this effect is not actually due to an improved motor ability of the right hand giving the response but much more of the stimulus itself.

Is the required left-right judgment congruent with the side of the button? Congruent would mean that the left arm is presented on the left side of the visual field and requires a left-thumb press while on the other hand a back view figure at 180° with its left arm extended requires a "contralateral" thumb response (incongruent). Considering the implications for the picture and depth plane, this congruency effect has most probably lead to an increased VIEW-effect.

Effect of Body Position

FRIEDERICI AND LEVELT (1990) tested subjects under a condition where gravitational information was present but irrelevant to the task being solved (subjects were in a horizontal supine position) and found that subjects are flexibly using cues other than gravitational ones as references when those could not serve as a referential systems. In this case participants base their response on head-retinal coordinates as a primary reference showing that they are able to switch to a reference frame other than the one used normally when standing upright. An interesting finding is that when subjects conducted the task with supine and with tilted head, lower RT resulted than when the head was aligned with the body. This suggests that subjects do not gain facilitation from the fact that the head-retinal and the body-defined axes are aligned and the authors suggest that when spatial assignment is required this leads to a higher computational load.

The side position was the only condition to trigger altered performance, showing a shift of RT patterns. This shift accounted for the interaction effect between body position and angle of rotation. The increased reaction times for angle of rotation 135° of the body figure remains to be fully explained; however it seems to be a matter of visual compensation that needs further exploration. When considering the A-phenomenon, a clarification of the question of "where is upright" and "where do we rotate to be able to make laterality judgments" is inevitable. In the other positions tested (supine, prone, upright) mental rotation strategies seem to be the same and do not lead to worsened or improved performance. The position 180° was of special interest because it could be considered "closer" to the actual position of the participant in the supine and prone condition, yet neither average RT (faster response), nor SD (more consistent) nor ER (less mistakes) showed significant effects of the factor POS. This suggests that participants are capable to abstract from their actual physical position. Individual analysis however suggests that an increased amount of individuals (16 out of 24) apply "flipping" mechanisms in EXP POS-DEPTH compared to EXP POS-PICT (where only 3 out of 13 show this decrease of the 180° position in relation to the neighboring positions 135° and 225°). Most strikingly, they show this behavior more often in the conditions PRONE and SUPINE (see Table 7) which indicates that performance was nevertheless altered for some of the participants during these positions. PARSONS (1987A) suggests that participants use a shortest-path mechanism and some of my participants explicitly mentioned doing so. This implies that a short-cut analogue to the flipping strategy is conceivable (KANAMORI & YAGI, 2002; MURRAY, 1997) where instead of going through all of the intermediate representations an efficient flipping increases performance speed, so that the front view figure at 180° results in a back view figure of 0° angle of rotation. Another explanation is that a front view figure at 180° is not perceived as inverted but more as a figure lying on its back (e.g. JOLA & MAST, 2005). A major part of the participants report tilting backwards into an imaginary supine position to solve this task.

Average reaction times as well as error rates generally show in the same direction, the larger the reaction times, the larger the error rates. This is remarkable as an accuracy-tradeoff mechanism would predict that the lower the reaction times, the higher the error rates. When participants need more time to react, one should expect error rates to decrease. Participants however show improved performance in the course of the experiment with a general decrease of reaction times. This corresponds to findings of various studies on mental rotation (e.g. COOPER 1975; JOLA & MAST, 2005; PARSONS, 1987; VOYER, 1995). Participants learn quite fast and get faster, yet the effect of orientation remains. Also, augmented speed obviously does not concurrently lead to diminished error rates.

The data corresponds well with results of previous studies on mental rotation of body figures (PARSONS 1987A, JOLA & MAST, 2005). In contrary to the results of the study by ZACKS ET AL. (2000) reaction times are perspicuously shorter and there is a more extensive effect of orientation as seen in studies using objects (e.g. COOPER & SHEPARD, 1973). Similar functions are found with left-right-judgments of hands and feet (Parsons, 1987b). Rotation angle 0° is easy to respond to. Yet, when considering a shape-matching process, the back view of a human figure is much more compatible and easier to respond to by simply adopting its position through translational transformation. Comparison with the front view figure requires an additional yaw-rotation of 180° which leads to the increased reaction time rate (JOLA & MAST, 2005; PARSONS, 1987A). Increasing angular disparity would then result in a kind of spinning movement for the back view figures and a "screw-like" movement for the front view figures. Most interestingly, reaction times at 180° are shorter for front view than for back view figures.

Further research could take a closer look at the effect of gravity by implying gravity with the environment of the stimulus: an upright figure could be presented in a tilted house (comparable with the side position tested here) or a figure could be presented as if lying on a beach towel (comparable with the supine position) or on a bed required for a massage (comparable to the prone position). This could be compared with the data gathered here.

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4. Influence of Instruction on Mental Rotation of Body Figures: A Top-Down Effect

Abstract

Are participants suggestible to allocentric transformation when this is innate to the human body figures they are to rotate? The following experiment tests the flexibility and suggestibility of strategies altered by the stimuli used and the instruction given. In a mental rotation task of human body figures, 16 participants are to decide if a human figure is showing the hand for a correct handshake or not which resembles a more allocentric task compared to traditional left-right decision tasks which are supposed to trigger egocentric transformations. The required imagining of shaking the figure's hand is supposed to render the front view more easy compared to the back view (change of perspective). The task is explored for figure rotations in the picture and depth plane. Results show that reaction times show a trend towards a reversal of the view effect found in previous experiments. Furthermore, the picture plane rotation no longer shows an interaction effect between view of the figures (front, back) and angle of rotation favoring the assumption that spatial compatibility (congruency of button press and laterality judgment) could be relevant for interpretation of the data.

Introduction

Studies dealing with imagery experiments discuss different kinds of transformations when studying mental rotation of body figures (e.g. BROCKMOLE & WANG, 2003; PARSONS, 1987A; ZACKS & TVERSKY, 2005). ZACKS ET AL. (2002) suggest two different neural systems for the two classes of mental spatial transformation; the *object-based spatial transformation* relates to rotation or translation of an object relative to the reference frame of the physical world (here referred to as allocentric) and *egocentric perspective transformation* that deals with the rotation or translation of ones' own point of view relative to the environmental frame of reference. ZACKS AND TVERSKY (2005) distinguish two kinds of instructions: in a direct instruction participants are requested to imagine a specific transformation process and to give responses in accordance with these. In a judgment task there is no specific instruction and transformation is inferred from reaction time patterns and error rates. Yet, the way the instruction is given is quite important (BROCKMOLE & WANG, 2003; CREEM ET AL., 2001B; SIRIGU & DUHAMEL, 2001; ZACKS & TVERSKY, 2005). It is further assumed that the type of task influences mental transformation processes by triggering egocentric (first-person) or more object-centered transformations (third-person).

In a study by ZACKS ET AL. (2000) instruction to do a left-right decision task is reported to trigger egocentric transformation processes, while a matching task with same-different (mirrored-non-mirrored) responses leads to object-based transformations. This difference in instruction (and task) indeed leads to strikingly different patterns of reaction times in relation to the angle of the presented figures. While the same-different task leads to a nearly linear increase of reaction times with increasing angular disparity which is more or less isomorphic to a corresponding physical rotation, the left-right decision task shows a more or less flat reaction time pattern across all angles of rotation.

Does a more allocentric instruction lead to altered reaction time patterns and does the modified instruction and figure lead to a change of mental rotation strategies? Are the effects of view and the interaction between view and angle as found in the previous left-right decision task experiments reversible if – instead of left-right decision task – a handshake is required to be judged as being correct or incorrect? The instruction is supposed to reverse the effect found in previous experiments for the entire spectrum of angles or rotation, where it takes longer to decide which arm is extended when figures are facing the observer (front view) due to the necessary YAW-rotation needed for the response of "which arm is extended". Back view figures are directly matched to the observer's orientation. If the task is to decide if the figure is extending the arm for a correct or incorrect handshake, front view figures should be easier, rendering the extra YAW rotation obsolete. To deepen the insights gained in EXP PLANE, presented figures are not only rotated in the picture plane (about the x-axis), but also in the depth plane (about the y-axis, see Figure 29).

Experiment HANDSHAKE

Method

Participants

Sixteen (6 female, 1 left-handed, mean age 28.4 years, range 22-38 years) healthy volunteers participated in the experiment. All subjects had normal or corrected to normal vision and they were naïve with regard to the hypothesis under investigation. 8 had already participated in a previous mental rotation experiment (Subjects # 2, 11, 20, 25, 38, 40, 53, 55).

Material and Procedure

Naturalistic human body figures (created by a 3D figure design program, Poser 6) are presented at eight different ANGLES of rotation (0°. 45°, 90°, 135°, 180°, 225°, 270°, 315° coded clockwise for the picture plane condition (PICT) or frontward for the depth plane condition (DEPTH) and in two different perspectives (front, back). Each picture shows a human body with one arm (left or right) extended away from the body's midline in a "hand-shake"-manner and the

Figure 46 Examples of Human Body Figures, LEFT: in the PICT plane (shown 135°) and RIGHT: DEPTH plane (shown 45°)

other arm along the body's side (see Figure 46).

Each ANGLE of rotation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), VIEW (front, back) and the number of left and right responses (left, right) appear equally often and the ORDER of presentation is randomized in nine consequent blocks and balanced throughout the experiment (=288 judgments per condition, presented with SuperLab Pro 2.0 (Cedrus Corporation, 1999).). Figures are presented on a flat screen (PC Intel Pentium III processor, 750 MHz, 256 MB RAM with a resolution of 1024 X 768 pixels), mounted in front of the subject's head. A cardboard tube is attached to the screen leaving the participants viewing only a circular view of the screen. Eye to monitor distance is kept at a constant 40 cm which leads to an angle of vision of 15.7 deg (stimuli size at 0° =11cm) and a chin rest ensures a stable position. The figures remain visible until the response is made and are followed by an inter-stimulus interval of 1000 ms.

Task. The participants have to decide if the figure is reaching out the right or wrong hand to shake hands (correct-incorrect discrimination). Half of the participants are instructed to press a button of a serial mouse with their left thumb if they think the figure is "offering a correct handshake" and they press with their right thumb if they think the figure is "offering the incorrect hand" for a decent handshake. The other half receives the opposite instruction which is to press with their right thumb to indicate a correct and the left thumb to indicate an incorrect handshake. All participants are made familiar with the task prior to the experiment by completing a short practice trial before the main experiment begins in each condition. They do not receive feedback regarding accuracy. For the following test trials they are repeatedly encouraged to decide as quickly as possible while remaining as accurate as possible. The serial mouse is placed in both of their hands with their arms resting on the table.

In a within design, two experiment conditions are conducted and balanced throughout the experiment: in the condition PICT PLANE human figures are rotated about the x-axis (ROLL, see Figure 29) and in DEPTH PLANE human figures are rotated about the y-axis (PITCH, see Figure 29)

The experiment lasted about 10-15min per condition (DEPTH took significantly longer) which lead to a total of 30min.

Results and Discussion

Data exclusion criteria:

- Cut-off criteria of 9s lead to an exclusion of .02% of all data.
- For RT analysis only correct responses are taken into account. Error rates are on average 4.9%.
- F-values from ANOVAs lower than 1 ($F < 1$) are not interpreted because the variability within the conditions was higher than between conditions. A Greenhouse-Geisser correction was applied when Mauchly's W reached a significance level of $p < .05$.

Subjective Reports

The task is clearly a more allocentric task compared to the previous experiment which applied a left-right-decision task. Participants here report more often that – without being instructed to do so – they rotate the figure so that they are facing them, instead of taking over the perspective of the stimuli. All participants report the depth plane condition to be harder which is in line with behavioral data for the depth plane. They report most effort for stimulus orientations below the horizontal plane (transversal, rotation angles 225°, 135°, 180°) and views where only the soles of the figures shoes are visible (rotation angle 270°) and report that these are quite unusual and therefore unfamiliar and unnatural views of a human figure.

Since the factor VIEW[22] can not be directly compared and coding of rotation angles is arbitrary, a separate analysis of the two rotation planes PICT and DEPTH is given further down. Nevertheless, assuming that people would re-orient any stimulus orientation back to the upright no matter if it is rotated to the back-front or left-right, mirrored angles (angles to the left and right (PICT) as well as to the front and back (DEPTH) (45°-315°, 90°-270° and 135°-225°) are grouped and analyzed together to give an impression of plane-differences (see Figure 47).

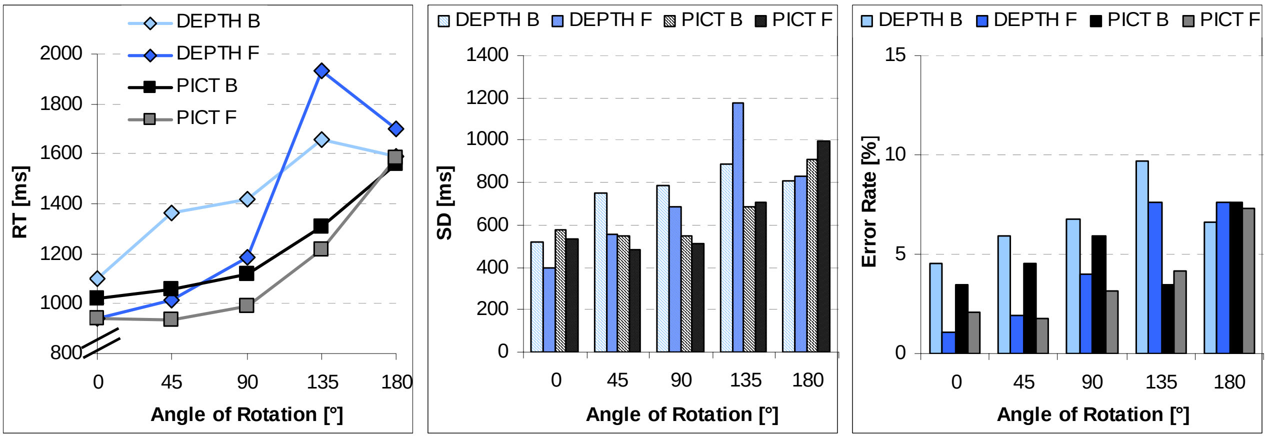

Figure 47 LEFT: average RT, **MIDDLE:** average SD, **RIGHT:** average Error Rate. All shown separately for front and back view figures and with standardized ANGLES of rotation (front, back (DEPTH PLANE) and left, right (PICT PLANE) grouped together (N=16).

Main effects

A three-way analysis of variance (ANOVA) with repeated measures with the within factors PLANE (DEPTH/PICT), VIEW (front, back view) and ANGLE (0°, 45°, 90°, 135°, 180°) was conducted and lead to the following results:

There was a main effect of the factor **PLANE** as regard to RT (F(1,15) = 10.02, $p < .01$, η^2=.40) but not regarding SD (F(1,15) = 4.17, $p = .059$) or ER (F(1,15) = 2.39, $p = .143$).

The factor **VIEW** was not significant for RT (F(1,15) = 2.91, $p = .109$) or SD (F(1,15) = 1.13, $p = .305$) only the measure of ER showed minor significance (F(1, 15) = 7.40, $p < .05$, η^2=.33).

The main factor **ANGLE** of rotation was highly significant for all measures taken: RT (F(1.25, 18.70) = 46.23, $p < .001$, η^2=.76), SD (F(1.91, 28.63) = 19.95, $p < .001$, η^2=.57) and ER (F(4,60) = 8.50, $p < .001$, η^2=.36).

There was a significant interaction effect of the factors **PLANE*ANGLE** for the measures RT with F(1.50, 22.51) = 11.52, $p < .01$, η^2=.43, SD with F(1.50, 22,42) = 8.33, $p < .01$, η^2=.36 and

[22] A closer look at the DEPTH condition reveals that there is a strong asymmetry between frontward and backward positions which questions the grouping.

for ER with $F(2.50, 37.48) = 3.12$, $p < .05$, $\eta^2=.17$. The interaction of the factors **VIEW*ANGLE** was also significant for RT ($F(2.92, 34.39) = 10.60$, $p < .001$, $\eta^2=.41$) and SD ($F(4, 60) = 7.07$, $p < .001$, $\eta^2=.32$) but did not reach significance ER($F(2.11, 31.58) = 1.66$, $p = .205$). The interaction effect **PLANE*VIEW** did not reach significance for any of the measures taken (all $F < 1$).

Generally, the DEPTH PLANE condition evoked significantly more errors than the PICT PLANE condition.

Effect of Experience/Training/ORDER

An analysis of **ORDER** did not show a significant effect, neither for RT; $t(15) = 2.08$, $p = .055$) nor was there a significant improvement reflected in the ER ($t(15) = 1.69$. $p = .112$).

However, as in EXP PLANE, a highly significant improvement (lower RT) was noticeable within the experimental condition (first four blocks vs. last four blocks) with $t(15) = 4.55$, $p < .001$ for the DEPTH PLANE condition and with $t(15) = 3.12$, $p < .01$. Error Rates again did not significantly lessen in the course of the condition (both $p>.066$). This result suggests that training effects do not seem to be transferred to the next condition but a speed-up takes place within the same condition.

PICT PLANE

The factor **VIEW** was not significant for any of the analyzed measures (RT ($F(1,15) = 2.56$, $p = .130$), SD ($F(1,15) = 2.01$, $p = .177$) and ER ($F(1,15) = 1.38$, $p = .258$). This is quite an interesting effect because it is different to the results of all previously described experiments in this work, where there is a clear advantage for back view figures for rotation angles up to 90°, respectively 270°. Despite the absence of a significant difference between front and back view figures, there seems to be a trend towards the expected reversed effect (compare Figure 48 with Figure 32)

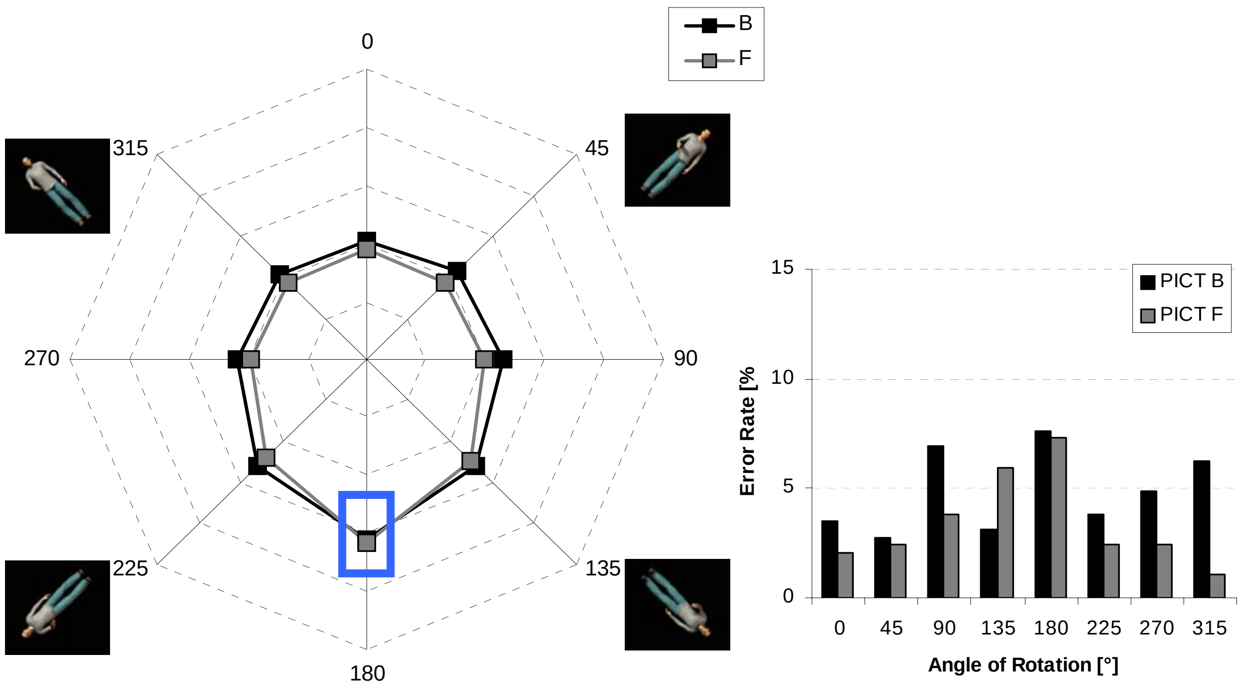

Figure 48 PICT PLANE: **LEFT**: RT (every layer equals 500ms), **RIGHT**: Error Rate. The square highlights the trend towards a reverse of the VIEW*ANGLE interaction effect found in previous experiments disappears when the instruction favours the front view figures (F) relative to the back-view figures (B).

There was a significant main effect of the factor **ANGLE** reflected in the analysis of RT ($F(1.62, 24.33) = 21.68$, $p < .001$, $\eta^2=.59$), of SD ($F(2.64, 39.60) = 7.19$, $p < .01$, $\eta^2=.32$) and also of ER ($F(7, 105) = 3.38$, $p < .01$, $\eta^2=.18$). Bonferroni-corrected pairwise comparisons of average RT of different ANGLES of rotation showed no significant asymmetry-effects for the comparisons of the ANGLES 45°-315°, 90°-270° and 135°-225 (all $p = 1$).

In contrary to the previous studies conducted, there was no significant interaction effect of the factors **VIEW*ANGLE** for all measures analyzed (all $F < 1$).

<u>DEPTH PLANE</u>

The factor **VIEW** was only significantly for Error Rates with $F(1,15) = 8.05$, $p < .05$, $\eta^2=.35$ but did not reach significance for the measures of RT ($F(1,15) = 2.37$, $p = .145$) and SD ($F(1,15) = 2.31$, $p = .149$). Inspection of Figure 49 reveals that the same reverse effect as noticed in the picture plane condition in previous experiments took place and back view figures now yield more errors than front view figures (also compare Figure 49 with Figure 33)

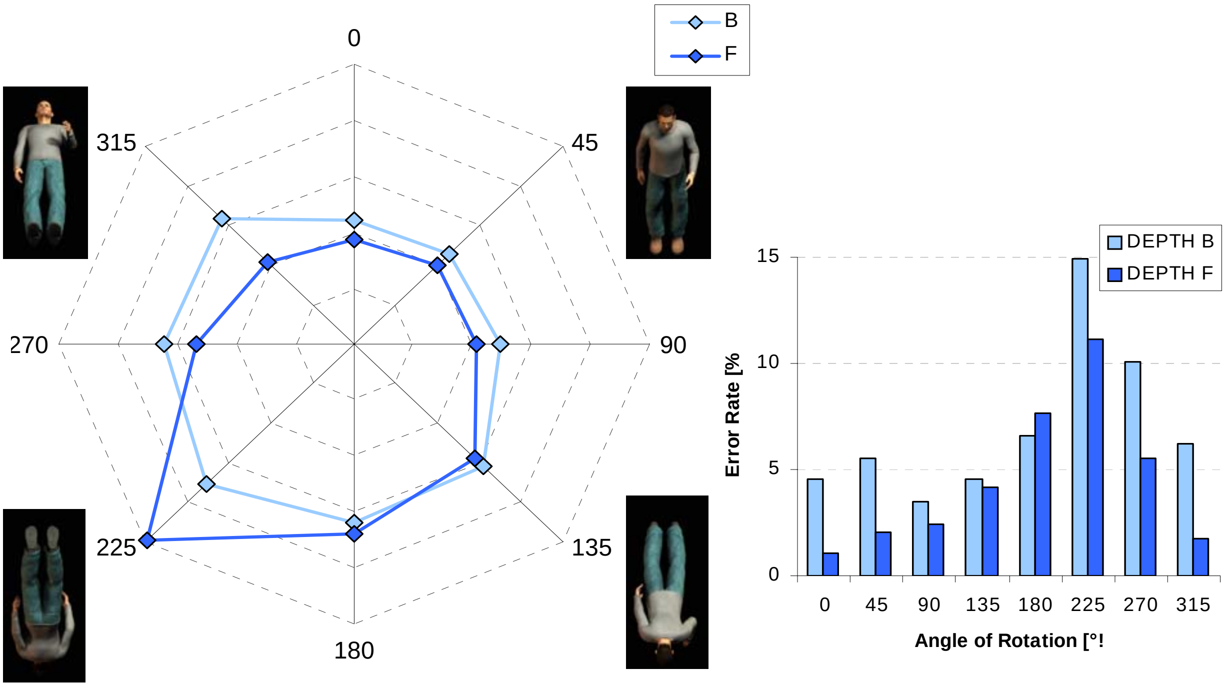

Figure 49 DEPTH PLANE: **LEFT:** RT (every layer equals 500ms), **RIGHT:** Error Rate

There was a main effect for the factor **ANGLE** reflected in RT ($F(2.95, 44.18) = 43.41$, $p < .001$, $\eta^2=.74$), in SD ($F(3.87, 58.00) = 13.44$, $p < .001$, $\eta^2=.47$) and in ER ($F(2.37, 35,50) = 6.21$, $p < .01$, $\eta^2=.30$). As is seen in Figure 49, there is a clear asymmetry between figures rotated to the front (45°-135°) versus those rotated to the back (225°-315°). Bonferroni-corrected pair-wise comparisons of average RT reveal significant differences of the different ANGLES 45°-315° ($p < .01$), 90°-270° ($p < .05$) and 135°-225 ($p < .001$). As in the previous experiments, reaction times for depth plane rotation again show a strong asymmetry with the peak of reaction times at 225° angle of rotation.

The interaction effect of the factor **VIEW*ANGLE** was highly significant for RT ($F(1.63, 24.22) = 14.38$, $p < .001$, $\eta^2=.49$), for SD ($3.24, 48.62) = 4.90$, $p < .01$, $\eta^2=.25$) but not for ER ($F(2.87, 43.04) = 1.04$, $p = .383$).

General Discussion

There was a general advantage of right responses (RT 11% lower compared to left-thumb responses). Various studies report an advantage of right-hand judgments over left hand judgments. PARSONS (1987A) compared vocal and manual left-right judgments and found the same strong side effect showing that this effect is not actually due to an improved motor ability of the right hand giving the response but much more of the stimulus itself. We assumed that participants instructed to use their right thumb to give the "correct" answer would be an advantage due to this side effect and even more so because this was the hand that they would have to reach out if they were to give a real handshake. This "handshake-advantage" effect however was not significant[23] (see Figure 50). This is in line with findings reported by DE'SPERATI AND STUCCHI (1997) where handedness has no influence on which hand is to give the response. They however find that when having to imagine the non-dominant hand grasping reaction times are significantly higher (which could be assumed to emerge when the instruction here had been to imagine shaking the figure's left hand).

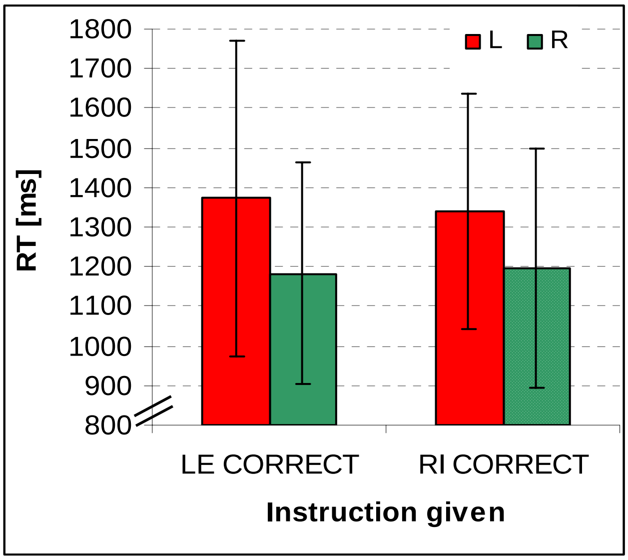

Figure 50 Instruction given did not lead to significant advantage of participants who could press with the right hand as if they were giving a correct handshake (i.e. RI CORRECT)

The clear VIEW effect reported in the previous experiments with figures rotated in the picture plane where back view figures are clearly easier was expected to be reversed by the handshake-instruction by yielding a more leveled pattern of RT across angles of rotation for front view figures and a clear orientation effect for back view figures. However, when comparing previous experiments double as many errors resulted in EXP HANDSHAKE, with 12% for front view as opposed to less than 5% errors for back view).

The altered instruction lead to altered reaction time patterns in both conditions: reaction times for front view figures however only show a trend to be shorter compared to the back view figures. Both views show almost identical reaction times in the picture plane condition. Unlike previous experiments, there is no significant effect of view when presented figures are rotated in the picture plane but the effect is now visible for depth plane rotations.

[23] This comparison is based on eight participants per group and needs to be taken into account and interpreted with caution.

A direct comparison of EXP PLANE was done for three participants who took part in both of the experiments: Figure 51 reveals that for these participants a reversal indeed seems to have taken place. Back view figures which are notably easier for small angles of rotation and show a strong effect of orientation in the picture plane in EXP PLANE are comparable to of front view figures in EXP HANDSHAKE (see LEFT TOP in Figure 51). On the other hand, front view figures start off at a higher level of RT and stay more or less leveled in EXP PLANE comparable to the back view figures of EXP HANDSHAKE (see LEFT TOP in Figure 51). The same kind of reversal is noticeable for the depth plane condition (see bottom LEFT and RIGHT in Figure 51).

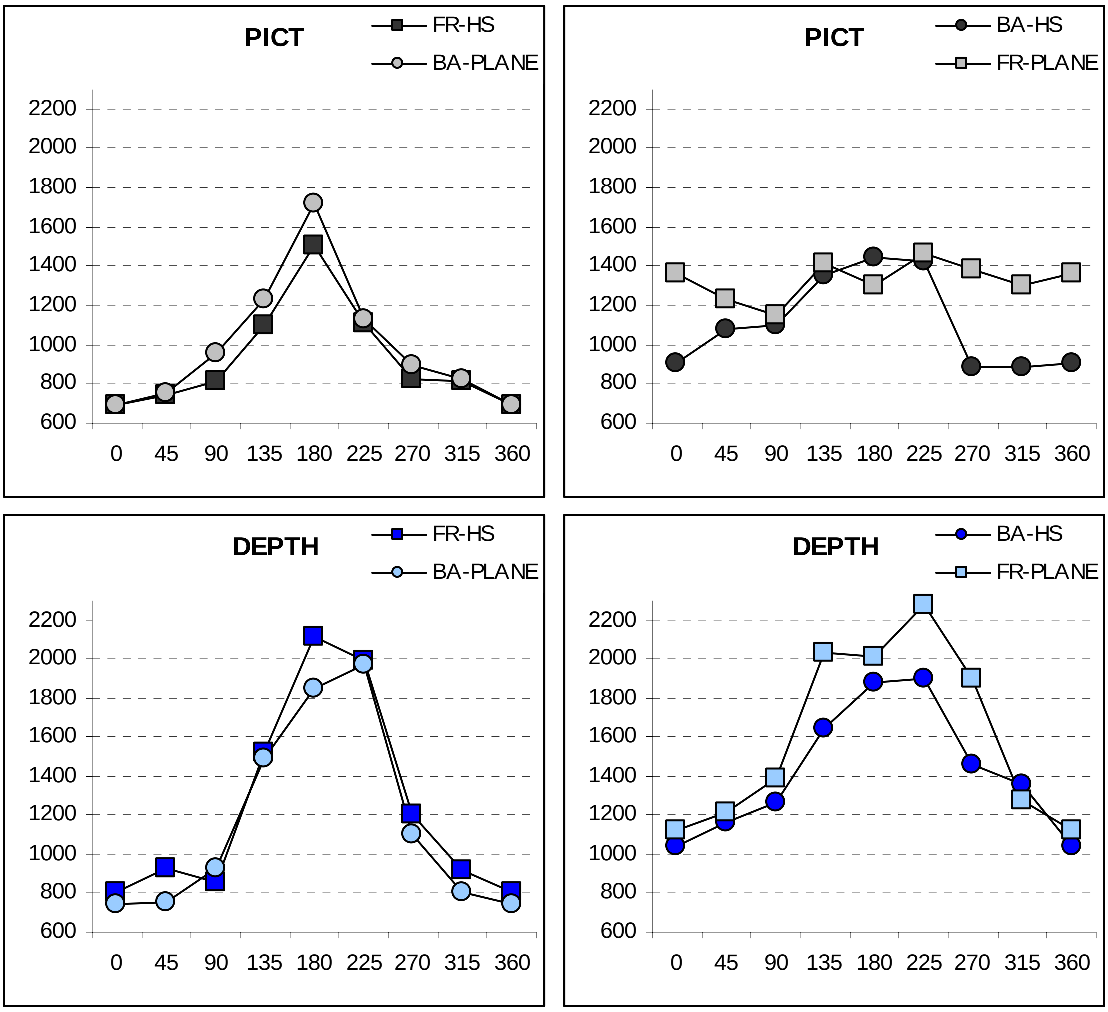

Figure 51 Data shown fort he three participants (#25, 53, 55) who took part in both EXP PLANE and EXP HANDSHAKE allowing a direct comparison and examination of possible reversal. Front view = FR, back-view = BA, EXP HANDSHAKE=HS, EXP PLANE=PLANE

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Zacks, J., Mires, J., Tversky, B. & Hazeltine, E. (2000). Mental spatial transformations of objects and perspective. *Spatial Cognition and Computation, 2*, 315-332.

Zacks, J.M. & Tversky, B. (2005). Multiple Systems for Spatial Imagery: Transformations of Objects and Bodies. S*patial Cognition & Computation, 5 (4)*, 271-306.

5. Object-Centered vs. Egocentric Change of Perspective in a Mental Rotation Task

Abstract

This experiment aims at triggering different spatial transformation processes by assessing mental rotation with cameras, where sixteen participants are explicitly instructed to imagine rotating the camera to the upright position (object-centered transformation) as well as with human body figures, where participants are asked to take of over the perspective of the figure (egocentric transformation). The results however reveal no significant difference between the two conditions.

Introduction

Earlier studies imply that characteristics of imagined spatial transformations of body figures are different to other objects (such as letters, numbers, two- or three-dimensional, abstract, or unfamiliar shapes). Judgments of body figures usually lead to an egocentric transformation. Here the observer changes coordinates and relation to both the object and the environment. HOWARD (1982) described egocentric rotation as a mapping of coordinates of one's body reference frame to another (i.e. hand to hand). Similar tasks with objects (such as letters; e.g. COOPER & SHEPARD, 1973; HINTON & PARSONS, 1981) usually evoke object-based transformation. In this kind of transformation, coordinates of the object differ and the environment-observer relation remains the same (ZACKS ET AL., 2000). HOWARD (1982) referred to this as an egocentric transformation and mapping of object-relative reference frames (WRAGA ET AL., 2003). Recent research has furthermore demonstrated the importance of imagined body movements for spatial judgment tasks about manipulable objects (DE'SPERATI & STUCCHI, 1997; KOSSLYN, GANIS & THOMPSON, 2001; WEXLER ET AL., 1998; WOHLSCHLÄGER & WOHLSCHLÄGER, 1998).

Neuropsychological findings imply that these two transformation strategies rely on different neuronal systems (ZACKS ET AL., 2000; WRAGA ET AL., 2003, 2005). Neuropsychological findings (RATCLIFF, 1979; TOMASINO, TORALDO & RUMIATI, 2003) show that lesions to the right posterior cortex impair the ability to rotate mental images of objects and lesions to the left posterior cortex lead to impairments in navigation tasks that require the participants to imagine body rotations. Additionally, recent neuro-imaging studies showed lateralized left-sided activation at the parietal-temporal-occipital junction when participants mentally rotated themselves compared to either an object-based mental rotation strategy (ZACKS ET AL., 1999; ZACKS ET AL., 2002; ZACKS ET AL., 2003) or a control condition, which required no rotation (CREEM ET AL., 2001B). In line with previous behavior studies WRAGA, CREEM & PROFITT (2000) report that participants are faster and more accurate at performing imagined self rotations than imagined object rotations. When participants make judgments about small manipulable objects, they show a strong tendency to use object-based transformations (ZACKS & TVERSKY, 2005). Experience with human bodies is more varied, including both object-like interactions and interactions in which one must estimate another's perspective.

PARSONS (1987A, 1987B) reported significantly lower reaction times for mental rotation of body figures in the picture plane compared to SHEPARD-METZLEr objects. The body analogy seems to be an advantage favoring embodiment processes and evoke a body image. This influences imagined transformation processes by giving them an advantage opposite to abstract objects (AMORIM ET AL., 2006).

ZACKS AND TVERSKY (2005) directly compared object-based transformations with perspective transformations by studying bodies and objects (cellular phones) and found differences in a left-right decision task where reaction times increased with orientation for pictures of phones but not pictures of bodies (always presented in the front view). Furthermore, the instruction was critical for the phone condition where the instruction to respond as if the phone was facing towards the participant yielded lower and more orientation dependant reaction times than the instruction to imagine holding the phone away from them (which is comparable with what I refer to as front view because it requires additional yaw rotation). The authors refer to the away condition with an egocentric perspective transformation because no rotation through the picture plane is required. This is surprising considering the finding of WRAGA ET AL. (2000) who report a general advantage of mental body rotation compared to mental rotation of objects, however find that object performance reaches near-viewer levels when rotations included haptic information for the turning object. In an fMRI study, WRAGA ET AL. (2005) investigated whether transformations conducted in these different frames of references are based on the same neural structures. Next to common activation of cortical regions they also found specific activation regions. An imagined object rotation task activated low-level motor areas, whereas imagined self rotation task did not (they used altered SHEPARD-METZLER objects). They found that egocentric transformation activated left supplementary motor region (SMA, Area 6) and object-centered activated left premotor area (M1, Area 6 and 4). These areas have previously been implicated in preparatory hand movements (e.g. RIZZOLATI, LUPPINO & MATELLI, 1996 (study with monkeys)). Moreover, several mental rotation studies have reported similar regions of activation in tasks in which participants imagined rotating objects with their hands, either explicitly or implicitly (KOSSLYN ET AL., 2001; WRAGA ET AL., 2003). It is likely that the activation limited to the left hemisphere is due to the fact that it controls the right hand (all of the participants in the study of WRAGA ET AL. 2005 were right handed). The results indicate distinct and multiple spatial transformation mechanisms within the human cognitive system and emphasize the flexibility of spatial processing mechanisms within the human brain.

In the previous experiments no specific instruction was given as to how participants were to fulfill their task. This experiment deals more deeply with this issue. Here participants are instructed to do either a object-centered rotation (rotate the camera up to the upright position and decide which thumb has to press the release button) or the egocentric transformation ("take over the perspective of the figure and decide which arm is extended"). Two aspects are of interest: are participants able to follow the instruction and do the resulting reaction times and error rates differ between the two transformation strategies?

Experiment OBJEGO

Method

Participants

Sixteen healthy volunteers (8 female, mean age 30.7 years, range 23-38 years) participated in the experiment. Three were left-handed (two female). All subjects had normal or corrected to normal vision and they were naïve with regard to the hypothesis under investigation. One subject (#20) had already participated in two other mental rotation experiments.

Material and Procedure

Naturalistic human body figures and pictures of a camera (created by a 3D figure design program, Poser 6) are presented in eight different rotation angles (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°; coded clockwise in the PICT plane) and in two different perspectives (front, back). Each picture shows either a human body with one arm (left or right) extended away from the body's midline and the other arm along the body's side (condition MAN) or a camera with the release button on the right (pointed out with red color) or left side (condition OBJ). This factor is referred to as **TRANS** in the following (see Figure 52).

Figure 52 Stimuli used for the factor TRANS; Example of Object (ANGLE BA225°, FR45°) and Body Figure (FR225°, BA315°). The red release buttons are pointed out with arrows in this figure, this was not necessary in the experimental conditions because the red button was clearly visible).

Each ANGLE of Rotation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), VIEW (front, back) and the number of left and right responses SIDE (left, right) appear equally often and the order of presentation was randomized in nine consequent blocks and balanced throughout the experiment (=288 judgments per condition, presented with SuperLab Pro 2.0 (Cedrus Corporation, 1999).). Figures are presented on a flat screen (PC Intel Pentium III processor, 750 MHz, 256 MB RAM with a resolution of 1024 X 768 pixels), mounted in front of the subject's head. A cardboard tube is attached to the screen leaving the participants viewing only a circular view of the screen. Eye to monitor distance is kept at a constant 40 cm which lead to an angle of vision of 15.7 deg (Stimuli 11cm at maximal height) and a chin rest ensures a stable position. The figures remain visible until the response are given and are followed by an inter-stimulus interval of 1000 ms.

In a within design, two experimental conditions are conducted and balanced throughout the experiment: in condition OBJ (object-based transformation) a camera with a highlighted button (red) is presented, while condition EGO (egocentric transformation) consists of human body figures with one arm extended.

Task. The participants' task is to decide which arm of the figure is extended away from the body's midline or which side they have to press the release button to take a picture (left-right discrimination). They press a button of a serial mouse with their left thumb if they think this was on the left or with their right thumb if they think this was on the right side.

- Instruction OBJ: "Flip the camera to an upright position as if you were going to take a picture (to the back view of the camera) and decide which thumb will have to press the release button."
- Instruction EGO: "Imagine yourself taking over the perspective of the figure and decide which arm you are extending."

All participants are made familiar with the task prior to the experiment by completing a short practice trial before the main experiment begins in each condition. They do not receive feedback regarding accuracy. For the following test trials they are repeatedly encouraged to decide as quickly as possible while remaining as accurate as possible. The serial mouse is placed in both of their hands with their arms resting on the table.

The experiment takes about 30min (15min each).

Results and Discussion

Data exclusion criteria:

- The cut-off criterion of 3s was applied. After a visual analysis of data one participant (male) was excluded from of analysis because his average RT was more than 1.5 times higher than the other participants and he obviously "did something else" (more than 50% of his responses were over 3s). The applied criteria of 3s lead to the exclusion of 1.9% of all the data of the remaining 15 participants.
- For RT analysis only correct responses are taken into account. Error rates low, on average these are 3.6% (OBJ: 2.8 %, EGO: 4.3%)
- F-values from ANOVAs lower than 1 ($F < 1$) are not interpreted because the variability within the conditions was higher than between conditions. A Greenhouse-Geisser correction was applied when Mauchly's W reached a significance level of $p < .05$.

Introspective Reports

Participants generally report the second condition to be easier; all in all this leads to no systematic difference of difficulty level between the two conditions.

Main effects

A three-way analysis of variance (ANOVA) with repeated measures with the within factors TRANS (OBJ/EGO), VIEW (front, back) and ANGLE (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) was conducted and lead to the following results (also see Figure 53):

The factor **TRANS** was not significant in any of the analysis (average RT, SD or ER (all $F < 1$). This shows that despite the precise instruction, participants seem to perform analogue transformations or are equally efficient no matter if they imagine moving something to their perspective or taking over someone's perspective to make laterality decisions. There was a highly significant main effect of the factor **VIEW** with $F(1,14) = 48.28$, $p < .001$, $\eta^2=.76$) for RT, $F(1,14) = 83.81$, $p < .001$, $\eta^2=.86$ for SD. This effect however was only minor significant for the ER analysis ($F(1,14) = 7.79$, $p < .05$, $\eta^2=.36$). In general, ER for front view (2.4%) figures was almost as high as that for back view figures (1.7%).

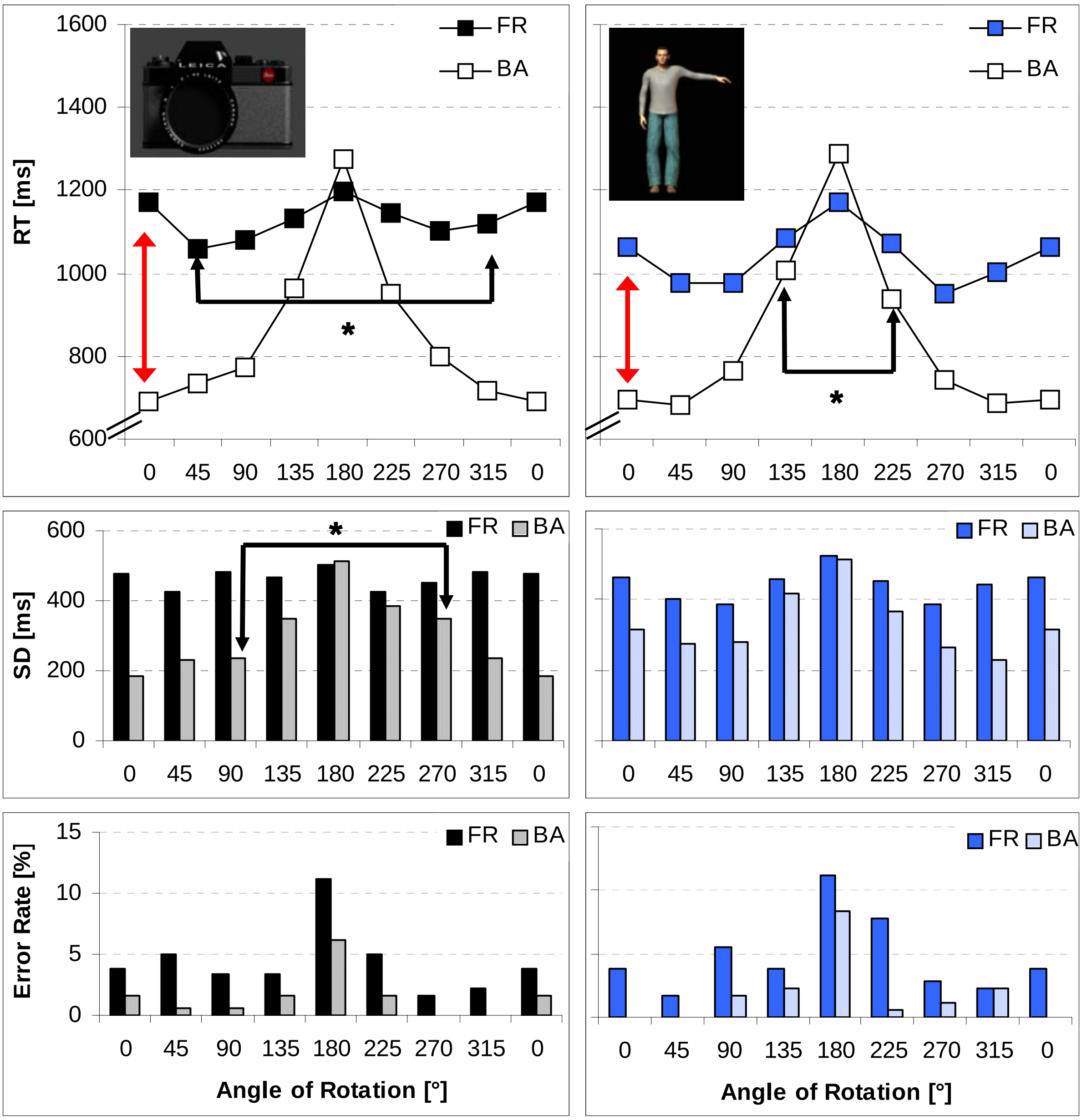

Figure 53 Average RT, SD of RT and Error Rate for **LEFT:** condition OBJ, **RIGHT** condition EGO; visual analysis already reveals that there are no significant main effects of the factor TRANS, yet the significant VIEW effect (FR=front view, BA=back-view) is obviously strong, as well as the effect of ANGLE of rotation which shows more strongly for back-view figures (RT: n.s. in condition OBJ, but $p < .01$ for EGO). (N=15)

There was also a highly significant main effect of the factor **ANGLE** for RT ($F(1.82, 25.52) = 50.43$, $p < .001$, $\eta^2=.78$), for SD ($F(3.48, 48.67) = 13.22$, $p < .001$, $\eta^2=.48$) and also for ER ($F(3.24, 43.92) = 10.71$, $p < .001$, $\eta^2=.43$). A separate analysis for the two TRANS conditions with the factor ANGLE of rotation exclusively for front view figures revealed that front stimuli do not show a significant orientation effect for the condition OBJ while this effect was clearly visible for condition EGO ($p < .01$).

There was a minor significant interaction effect of the factors **TRANS*ANGLE** reflected in the average RT ($F(3.57, 50.01) = 2.83$, $p < .05$, $\eta^2=.17$) but this effect did not reach significance in the measure of SD (4.11, 57.47) = 1.11, $p = .364$) or ER ($F(2.34, 33.51) = 1.22$, $p = .313$). The interaction effect **TRANS*VIEW** was not significant for any of the measures analyzed (all $F < 1$). As in previous studies, there was a highly significant interaction effect of the factors **VIEW*ANGLE** reflected in the analysis of RT ($F(1.96, 27.47) = 14.44.$, $p < .001$, $\eta^2=.51$) and SD ($F(7, 98) = 3.45$, $p < .01$, $\eta^2=.20$). This effect however did not show in the analysis of ER ($F < 1$).

The arrows in Figure 53 highlight the time presumably needed to conduct a 180° YAW rotation (on average this is a difference of 479ms for the upright orientation 0°).

Effect of Laterality

Of special interest in this experiment was if right-side judgments for the right camera button were even faster than the general SIDE effect noticed in previous experiments with human figures because custom-made cameras always have the release button on the right side of the camera.

A three-way analysis of variance (ANOVA) with repeated measures of average RT with the factors SIDE, VIEW and ANGLE separately analyzed for the condition EGO yielded a significant main effect of the factor **SIDE** ($F(1,12) = 6.12$, $p < .05$, $\eta^2=.338$), **VIEW** ($F(1,12) = 38.28$, $p < .001$, $\eta^2=.761$, **ANGLE** ($F(2.10, 24.11) = 37.07$, $p < .001$, $\eta^2=.755$ and a significant interaction effect of **VIEW*ANGLE** with $F(2.20, 26.44) = 5.16$, $p < .05$, $\eta^2=. 301$. There were no significant interactions with the factor SIDE.

The same analysis with average RT of the condition OBJ only showed a significant effect of the factor **SIDE** ($F(1.13) = 16.37$, $p < .01$, $\eta^2=.557$), **VIEW** ($F1,13) = 27.32$, $p < .001$, $\eta^2=. 678$, **ANGLE** with $F(1.96, 25.53) = 26.50$, $p < .001$, $\eta^2=.671$. The interaction **VIEW*ANGLE** was significant with $F(2.48, 32.29) = 11.82$, $p < .001$, , $\eta^2=.476$ and here, the interaction **SIDE*ANGLE** was close to being significant ($F(3.57, 46.50) = 2.66$, $p = .050$, $\eta^2=.17$). The hypothesis is that we are used to the right release button and that this response should be therefore favored. This can not be thoroughly confirmed due to the general advantage of right-sided responses. A comparison of the two conditions did not show a significantly lower response time of "right" answers of OBJ in contrary to EGO (highlighted with black arrows in Figure 54). The data reveal that the side effect is more pronounced in the back view figures for both of the stimuli used. This is in line with findings by DE'SPERATI AND STUCCHI (1997) who claim that the graspability of the object is strongly dependent on its orientation; the farther away the handle of a screwdriver, the longer the response time in their study. In

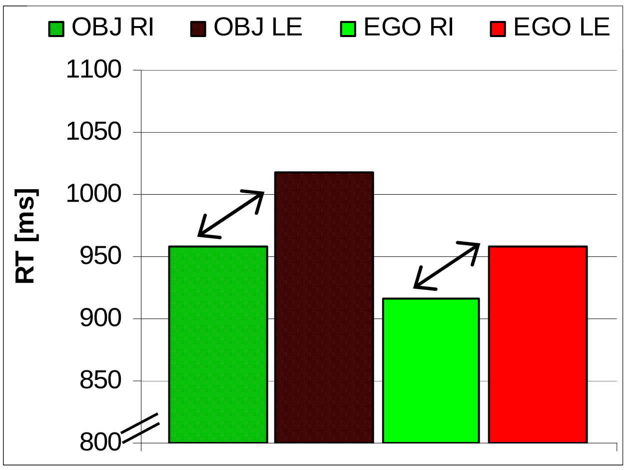

Figure 54 Right hand responses were always faster than left hand responses, this effect was comparable for the two conditions

addition, when the angle of the screwdriver implied a particularly awkward grip it takes longer than when viewing the corresponding more comfortable angle which suggests procedural knowledge to be involved.

Training effect

A Paired Samples t-test (2-tailed) of the factor ORDER revealed significant improvement from the first condition to the second (independent from what condition participants started with) with $t(14) = 3.83$, $p < .01$ (see Figure 55). Only one out of 15 participants showed increased RT in her second condition (VP#20). This reveals a systematic transfer effect.

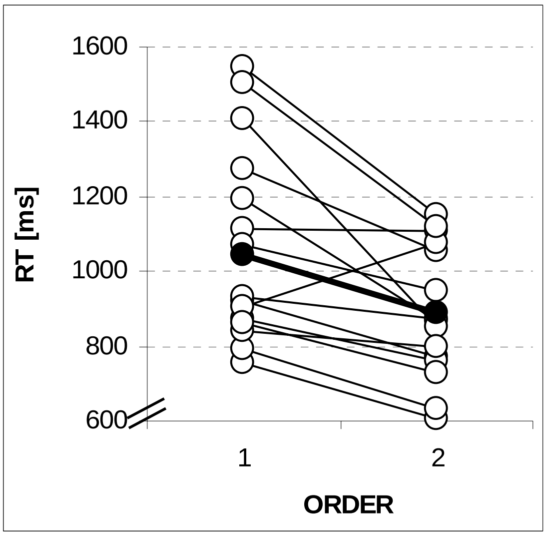

Figure 55 Significant improvement from the first condition to the second (white circles show individual data, black circles = average)

A two-way analysis of variance (ANOVA) with repeated measures with the within factors TRANS (OBJ/EGO) and BLOCKORDER (1-9) revealed a significant main effect of the factor **ORDER** with $F(8, 104) = 4.94$, $p < .05$, $\eta^2=.275$ (also see Figure 55) and a significant interaction effect of the factors **TRANS*BLOCKORDER** ($F(8, 104) = 2.50$, $p < .05$, $\eta^2=161$. Also, this significant improvement within the condition OBJ (comparison of first four blocks vs. last four blocks) with $t(14) = 3.13$, $p < .01$ did not appear within the condition EGO ($t(14) = .756$, $p = .462$ suggesting that the transfer effect was less prominent in the condition EGO. Figure 56 emphasizes this fact: participants significantly improve their performance in the course of the condition OBJ but not so in the condition EGO where they already start off at a very low level of RT and more or less stay at that level within the condition. WRAGA ET AL. (2003) find pronounced motor involvement in an object-rotation task if the preceding condition was to rotate hands but not if it was to rotate objects. I explicitly gave the instruction to rotate the camera to the upright position and results show that there was a trend towards an implicit transfer (e.g. stronger motor involvement leading to decreased RT and lower ER): participants who conducted the condition EGO after the condition OBJ show a more pronounced decrease of RT compared to the participant doing the experimental conditions in the other order. A three-way analysis of variance (ANOVA) with repeated measures performed on the data[24] with the between factor ORDER (OBJ→EGO, EGO→OBJ) and the within

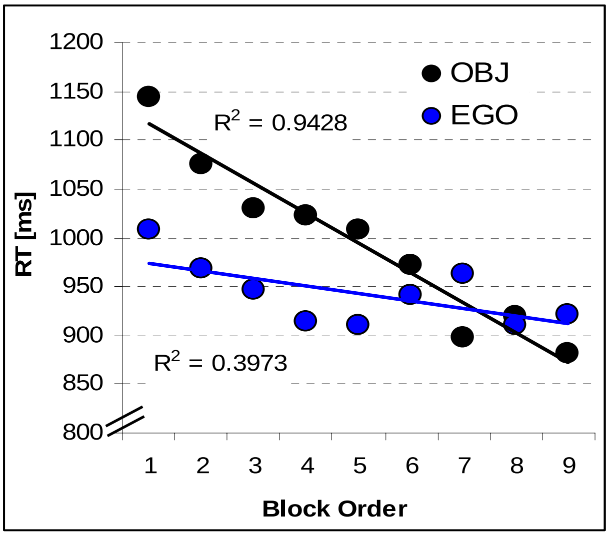

Figure 56 Decrease of RT is different for OBJ and EGO

[24] It has to be considered that this analysis is based on only 8 participants per group.

factors TRANS (OBJ, EGO) and ANGLE of rotation yielded no significant effect of the between factor ORDER with $F(1,14) = 1.42$, $p = .253$, $\eta^2=.949$. Yet, there was a significant effect of **ANGLE** ($F(7, 98) = 53.51$, $p < .001$, $\eta^2=.793$) and significant interaction effect of the factors **TRANS*ORDER**[25] ($p < .01$), and **ANGLE*ORDER** ($p < .05$).

The specific instruction to conduct an object-based transformation did on average not lead to any different results than when participants were to take over the perspective of a given figure. This strongly suggests that the same rotation mechanisms were applied given the fact that "to-be grasped" objects yield reaction time patterns distinct to "to-be-observed" objects (DE'SPERATI & STUCCHI, 2000). In their study, they found significant differences between when participants were to visually judge a screwdriver as a clock hand moving clockwise or counterclockwise or when they had to decide whether a screwdriver was screwing or unscrewing. They found distinct asymmetries for the latter task where the position of the handle relative to the observer was of significant importance for performance. Post-hoc analysis revealed significant symmetry differences for condition OBJ as well as for EGO, yet these were more accentuated in the former condition. When comparing the "mirrored" positions 45°-315°, 90°-270° and 135°-225°, there were significant effects of asymmetry found most pronounced for the back view figures/objects:

- for cameras with the release button located on the left side (all $p < .05$)
- for cameras with the release button located on the right side (135°-225°, $p < .01$)
- for human figures with their right arm extended (90°-270° and 135°-225° both $p < .05$)

The fact that these positions shows the release button/arm further away from the participant and the additional difficulty of pressing the unusual side of the camera could have lead to this result. The reduced effect for positions close to upright with the release button on the right suggests that these views are better "trained" and less subject to confusion.

Possibly, the instruction to "imagine to flip" the camera to the upright position should have been expanded to a condition where the "graspability" is more hidden and the task is given to rely on more visual strategies. This could be done according to SIRIGU AND DUHAMEL (2001) who found different reaction time patterns when hands were placed on participants lap or were to hold behind their back (i.e. a "blocking" of embodiment processes). The authors distinguished between participants imagining their hand moving (motor imagery) or recall of the image of a hand from memory as an external object (visual imagery). As for rotation of a hand at an incompatible position the former strategy (first person instruction, e.g. "imagine yourself looking at the back of your left hand, fingers pointing down") lead to faster response than a third-person instruction ("imagine yourself looking at the back of my left hand, fingers pointing down"). The authors found improved performance for third-person instruction when participants were to hold hands behind their backs ("incompatible posture").

We suggest that the camera triggers different transformation mechanisms than abstract objects because people mentally grasp the object (DE'SPERATI & STUCCHI, 1997, 2000) and therefore transformations are similar to what HOWARD (1982) described as egocentric transformation; a mapping of coordinates of ones body reference frame to another (i.e. hand to hand). We suppose

[25] Linear within-subject contrasts for TRANS*ORDER are (1) = 17.53, $p < .01$, $\eta^2=.556$.

that the motor activation is quite similar to motor activations found in body transformation tasks. For same-different tasks, imagined movements seem to be more important (WEXLER ET AL., 1998; WOHLSCHLÄGER & WOHLSCHLÄGER, 1998; ZACKS ET AL., 2000) and this is in line with the findings by WRAGA, CREEM AND PROFFITT (2000) who found near-viewer levels of reaction times when rotations of objects included haptic information for the turning objects. Another explanation could be that recognition processes are more relevant for the front view of the stimuli and that the back view stimuli evoke more pronounced parallel matching processes.

It is quite surprising that the condition with objects yielded no orientation effect for front view figures while this effect was clearly visible for human figures. This contradicts previous studies on object transformations however MURRAY ET AL. (1993) also reported that speed of transformation of familiar objects is much faster for familiar objects than for novel objects.

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6. A 3D-Model of Mental Rotation of Body Figures

Abstract

Left-right discrimination is essentially dependent on perspective. Perspectives which do not correspond directly sometimes afford mental operations to discriminate left from right (RIGAL, 1996). In contrary to PARSONS (1987A), ZACKS ET AL., (2000) apply only front view (figure facing the observer) stimuli. In what they refer to as the egocentric perspective transformation (left-right decision task) the authors do not find orientation effects. Reaction times are high and flat. This implies that egocentric judgment in a left-right task with rotated human figures is independent from angular disparity. PARSON'S data (1987A, 1987B) do not conform to this view. In his study on body or body part transformation reaction times are always dependent on how far orientation of a figure deviates from the orientation of the observer and on the different axes of rotation. This experiment aims at expanding the space of presented angles of rotation and in a left-right decision task 21 participants are to respond to figures rotated in the depth or picture plane of figures showing from the front, back, left or right side. The patterns of analyzed measures (RT, SD and ER) show similar effects as when different planes of rotation were presented in separate conditions.

Introduction

Left-right discrimination is essentially dependent on perspective. Perspectives which do not correspond directly sometimes afford mental operations to discriminate left from right (RIGAL, 1996). ZACKS ET AL. (2000) apply only front view (front facing) stimuli. In the egocentric perspective transformation (left-right task of body sketches) the authors do not find orientation effects. Reaction times are high and flat across all angles of rotation. This implies that egocentric judgment in a left-right task with rotated human figures is independent from angular disparity. PARSON'S data (1987A, 1987B) do not conform to this view. In his study reaction times of body or body part transformation are always dependent on how far orientation of a figure deviates from the orientation of the observer and of axes of rotation. Based on his data on body figure rotations PARSONS (1987A) makes the following predictions; reaction times are increased when the head is oriented: 1. Away from the observer or forward, 2. Away from the observer and beneath the transversal plane, 3. Upside down (180°) and 4. Upside down with the body closely parallel to the frontal plane of the observer (135°). Parsons (1987A) also puts emphasis on the fact that reaction time for a figure in an upside down position is dependent on its view (front/back). He states that with less familiar orientations it is possible that people imagine less efficient paths, take longer to find a path, or produce slower imagined spatial transformation. With bodies rotations about the vertical (z) axis are common in our daily lives and this familiarity may increase the rate of imagined rotation. This training effect is also clearly visible in a decreasing reaction times achieved with training in various mental rotation tasks. This more rapid rotation about the major principal axis of an object (here axis of elongation of the body) is more rapid than rotation about any other axes (METZLER, 1973).

The speed of mental transformation is relatively independent of complexity of an image (but absolute reaction times increase with complexity (SHEPARD & METZLER, 1988). Complexity is also mentioned by BAUER AND JOLICOEUR (1996) who find that complexity specifically influences slope of the RT-function (this assumption however was not confirmed by some researchers).

Can different strategies for distinct planes of rotation be better assessed and differentiated by testing various angles of position intermingled and randomly presented? Are switch costs visible? The mixed presentation aims at eliminating "logical" strategies by randomly presenting figures in eight positions per plane (45° steps rotated in the picture or depth plane) and four different positions in the yaw plane (front, back, left, right side of the body figure). The following experiment aims at expanding the investigated "space" with more naturalistic looking rotated body figures.

Experiment 3D

Method

Participants

Twenty-one healthy volunteers (8 female, 1 left-handed, mean age 28.6 years, range 23-37 years) participated in the experiment. All subjects had normal or corrected to normal vision and they were naïve with regard to the hypothesis under investigation. 9 subjects had already participated in previous mental rotation experiments (#1, 10, 11, 14, 20, 26, 42, 55, 86).

Material and Procedure

Naturalistic body figures (created by a 3D figure design program, Poser 6) are presented in different rotation angles in the depth, picture and yaw plane (45° interval steps, clockwise or to the front respectively) and in three different perspectives (front, back, left-side, right-side view) resulting in 112 figure presentations. Each picture shows either a human body with one arm (left or right) extended away from the body's midline and the other arm along the body's side (see Figure 57).

Each ANGLE of rotation of the figure (0°. 45°, 90°, 135°, 180°, 225°. 270°, 315°[26]), VIEW (front, back, left side, right side) and the number of left and right responses SIDE (left, right) appears equally often and the order of presentation is randomized in four consequent blocks and balanced throughout the experiment (=448 responses, presented with SuperLab Pro 2.0 (Cedrus Corporation, 1999).). Figures are presented on a flat screen (PC Intel Pentium III processor, 750 MHz, 256 MB RAM with a resolution of 1024 X 768 pixels), mounted in front of the subject's head. A cardboard tube is attached to the screen leaving the participants viewing only a circular view of the screen. Eye to monitor distance is kept at a constant 40 cm which lead to an angle of vision of 15.7 deg (Stimuli 11cm at fully upright position) and a chin rest ensures a stable position. The figures remain visible until the response is given and are followed by an inter-stimulus interval of 1000 ms.

[26] Angles are coded clockwise for picture plane rotations and to the front for depth plane rotations.

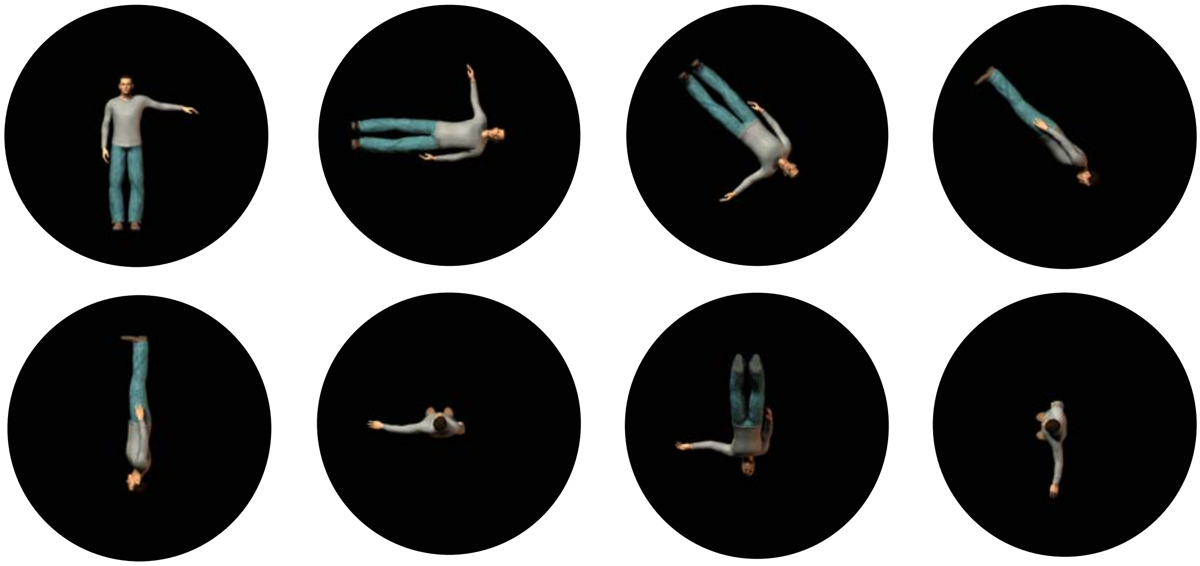

Figure 57 Human body figures used in Experiment 3D; **TOP** row shows rotations in the PICT PLANE: FR-LE-0°, FR-RI-90°, FR-LR-135°, RISIDE-LE-135°, and **BOTTOM** row shows rotations in the DEPTH PLANE: RISIDE-LE-180°, BA-LE-90°, BA-LE-225°, LESIDE-LE-90°. (FR= front view, BA= back-view, RISIDE= right side, LESIDE= left side, LE=left arm extended, RI=right arm extended)

Task. The participants' task is to decide which arm of the figure is extended away from the body's midline (left-right discrimination). They are instructed to always take over the perspective of the presented figure and conduct an "egocentric" transformation. They press a button of a serial mouse with their left thumb if they think the figure's left arm is extended and they press with their right thumb if they think the figure's right arm is extended.

Experimental Procedure. All participants are made familiar with the task prior to the main experiment by completing a short practice trial. The break never exceeds 5min and was supposed to ensure attention and motivation of the participants. They do not receive feedback regarding accuracy. For the following test trials they are repeatedly encouraged to decide as quickly as possible while remaining as accurate as possible. The serial mouse is placed in both of their hands with their arms resting on the table.

Before the experiment begins, handedness, dominant eye and preferred direction of rotation ("make a 360° turn about your vertical body axis") is noted to investigate correlations of laterality with possible asymmetrical mental rotation effects.

The experiment takes about 40min.

Results and Discussion

Data exclusion criteria:

- The cut-off criterion of 6s was applied which lead to the exclusion of 0.5% of all the data.
- For RT analysis only correct responses are taken into account. Error rates are on average 3.5% (PICT PLANE: 0.7%, DEPTH PLANE: 2.8%)

- F-values from ANOVAs lower than 1 (F < 1) are not interpreted because the variability within the conditions was higher than between conditions. A Greenhouse-Geisser correction was applied when Mauchly's W reached a significance level of p < .05.

Introspective Reports

As in previous experiments including depth plane rotation angle 225°, participants report problems with this position. An quite striking observation mentioned by two participants was that in beginning of the experiment they based their response on single body parts and for example focused on the shoulder or the face of the presented figure and after a while (after the break) increasingly decided by judging the figure in a more holistic manner. This reminds of earlier reports (EXP POS-PICT) where a participant (#5) reports looking at the chin and then after a while looking at the belly button. These participants seem to change their focus of attention to a more central view.

In the following, front, back, left-side and right-side views are analyzed and presented separately for the picture and depth plane.

PICT PLANE

As for the picture plane rotation I find lower reaction times for back view figures for small rotation angles up to 90° (or 270° respectively) and lower average RT for front view figures at larger angular disparities from upright. Front view figures remain more or less at the same level for all rotation angles. The RT curves for sideways presented figures (see right side of Figure 58) intersect and show a opposite effect at the angles 135° and 225°. This suggests that reaction times are generally lower for figures facing down and higher for figures facing up and this could imply that these positions are easier to "fall into". Imagining the according falling movement for the figures facing up would require falling backwards which seems to be more difficult.

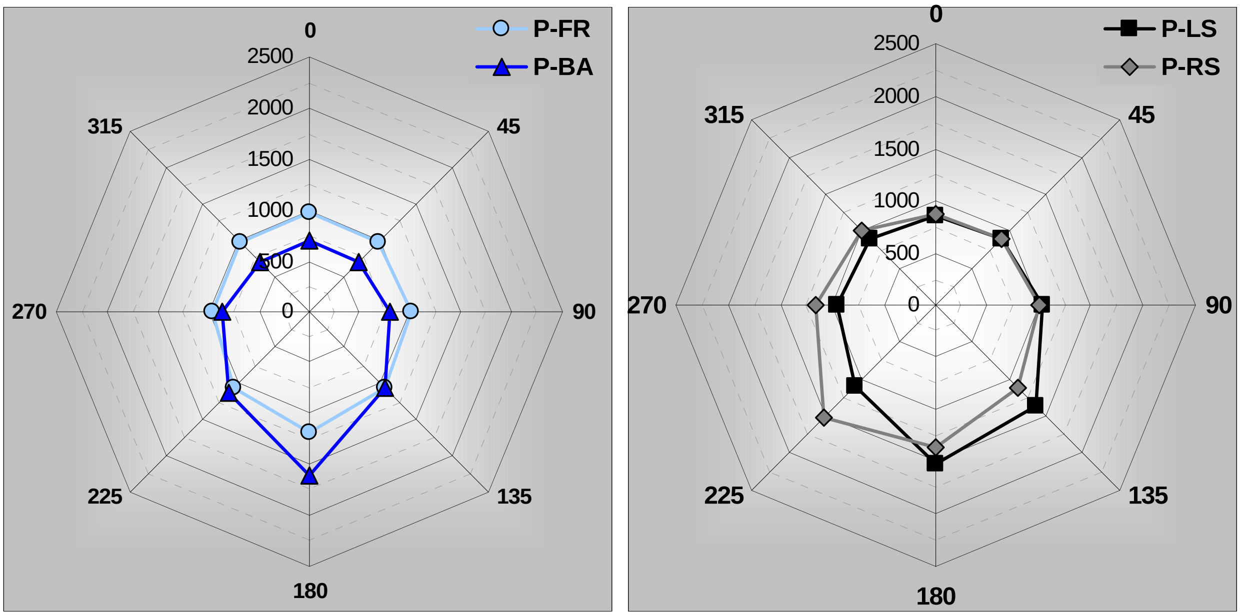

Figure 58 PICT PLANE; on the left side average responses to front and back view figures are depicted, on the right side the comparison of left-sided and right-sided figures.

An analysis of variance (ANOVA) with repeated measures with the within factors VIEW (FR, BA, LS, RS) and ANGLE of rotation (0°, 45°; 90°, 135°, 180°, 225°, 270°, 315) conducted with RT and ER separately reveals a significant main effect for the factor **VIEW** for RT with $F(3, 57) = 14.15$, $p < .001$, $\eta^2=.427$. Bonferroni-corrected pairwise comparisons reveal that this effect is due to the significant differences between BA-LS ($p < .001$), BA-RS ($p < .001$). Analysis of ER also shows this effect ($F(2.21, 42.07) = 5.53$, $p < .01$, $\eta^2=.225$).

There is a highly significant effect of **ANGLE** of rotation with $F(1.72, 32.71) = 62.71$, $p < .001$, $\eta^2=.767$ for RT and with $F(3.02, 57.37) = 6.15$, $p < .01$, $\eta^2=.245$.

The interaction of the two main factors **VIEW*ANGLE** is also highly significant with $F(21, 399) = 12.18$, $p < .001$, $\eta^2=.391$ for RT. This comparison does not reach significance for analysis of ER ($p = .433$).

As in preceding studies and in contrary to findings (e.g. ZACKS ET AL., 2002) a separate analysis of RT the front view figures alone (BA and FR only) shows a significant effect of orientation with $F(3.93, 78.60) = 4.80$, $p < .01$, $\eta^2=.193$. Bonferroni-corrected pairwise comparisons reveal that this effect is due to significant differences between the angles or rotation 135°-270°, 180°-270° and 180°-315° (all $p < .05$).

DEPTH PLANE

The pattern of RT for front and back view figures rotated in the depth plane shows a comparable pattern to the one we saw in EXP PLANE, where a strong asymmetry results with a peak of RT at 225° (compare Figure 59 with Figure 33). Again, it has to be considered that the terms front and back are based on the starting position of the stimuli leading to a front view figure facing away from the observer at 180° and a back view figure facing towards the observer at 180°. RT for front view figures is generally higher and the difference (on average 351ms) is assumed to reflect the yaw-rotation necessary to match one's own position with the figure. As for the sideways presented figures, there seems to be a slight advantage for left-side figures at 225° angle of rotation.

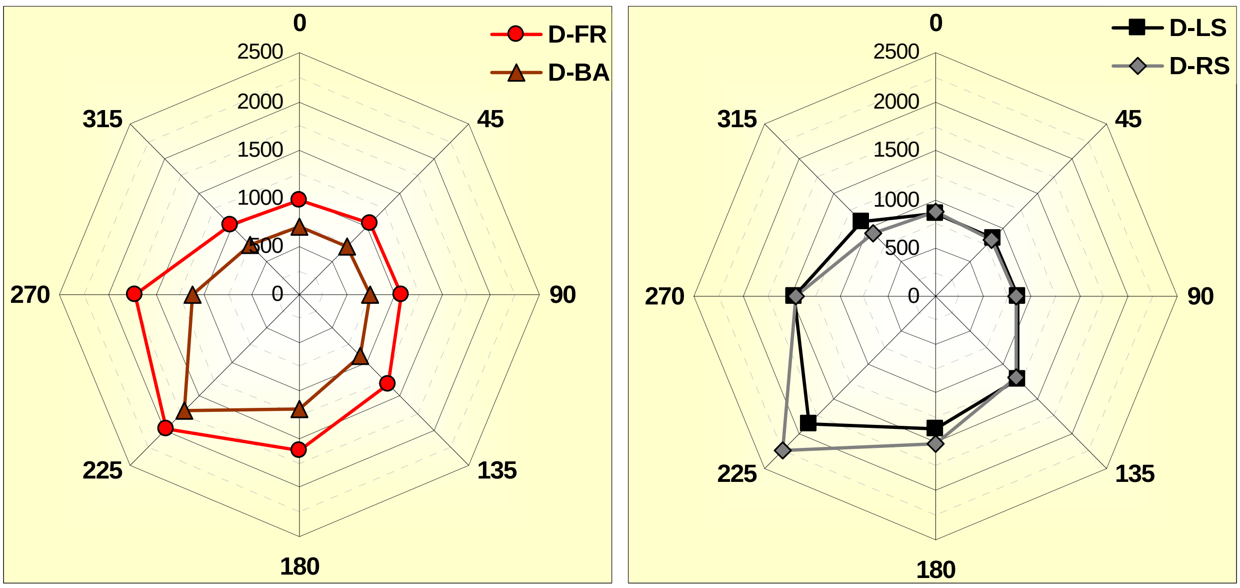

Figure 59 DEPTH PLANE; on the left side average responses to front and back view figures are depicted, on the right side the comparison of left-sided and right-sided figures.

An analysis of variance (ANOVA) with repeated measures with the within factors VIEW (FR, BA, LS, RS) and ANGLE of rotation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315) yielded a significant main effect of RT for the factor **VIEW** with $F(2.08, 35.41) = 17.00$, $p < .001$, $\eta^2=.500$. Bonferroni-corrected pairwise comparisons reveal that this effect is due to the significant differences between FR-BA ($p < .001$), BA-LS ($p < .05$), BA-RS ($p < .001$) and LS-RS ($p < .05$)[27]. This comparison does not reach significance for ER ($p = .109$).

RT and ER both also showed a highly significant effect of **ANGLE** of rotation with $F(2.84, 48.35) = 90.58$, $p < .001$, $\eta^2=.842$ for RT and $F(2.16, 41.01) = 25.69$, $p < .001$, $\eta^2=.575$ for ER.

The interaction of the two main factors **VIEW*ANGLE** is also highly significant for both RT ($F(21, 357) = 2.44$, $p < .001$, $\eta^2=.126$) and ER ($F(21, 399) = 4.82$, $p < .001$, $\eta^2=.202$).

The significant difference in reaction times found here between figures with their left side showing and figures with their right side showing seems interesting. We hypothesized that people might feel more comfortable "turning left", yet the data of preferred direction of rotation did not support this: 11 out of 21 participants turned left when they were spontaneously asked to make a 360° turn about their vertical axis, the remaining 10 preferred turning to the right. Still I speculate that given the fact that 90% of the participants are right-handed, a zooming and matching (one's right hand with the figure's right arm) might be easier to do with a left-ward turn.

Yaw-rotation in the picture plane

We were interested in investigating if the time course of yaw-rotation noted for upright figures, namely the rotation from the front to the back view, would indeed be "halved" by the side-views[28]. A comparison was made for every angle of rotation (see Figure 60) with the following formula:

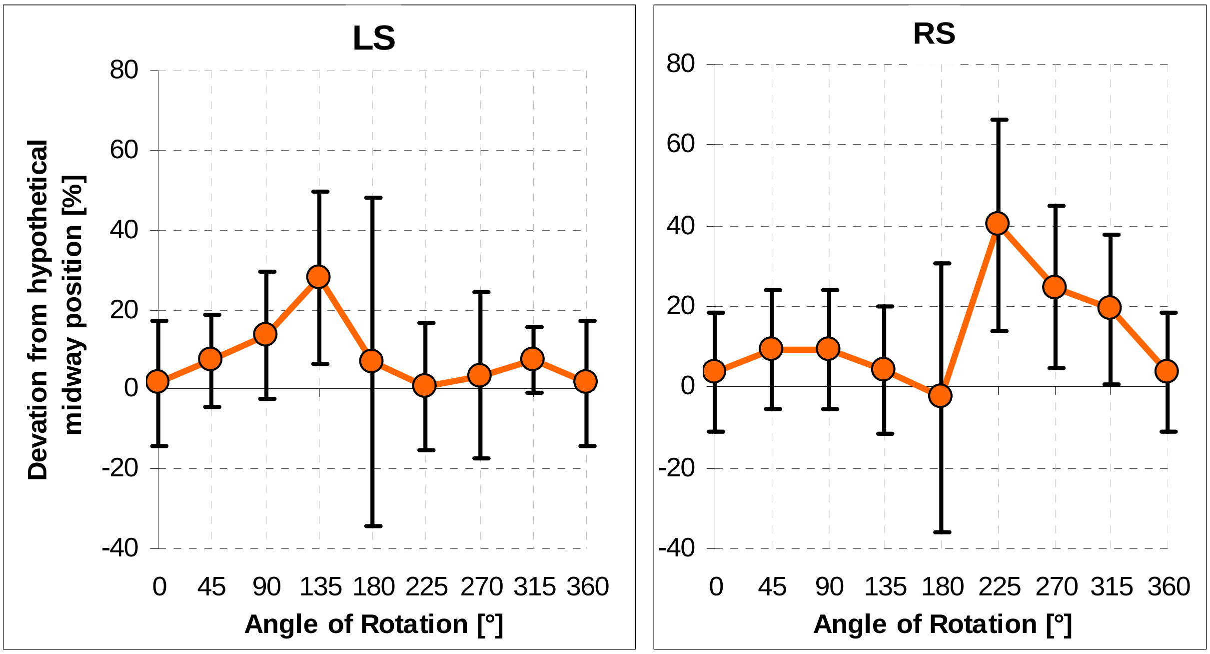

Figure 60 Deviation from hypothetical midway position shown for all angles of rotations and separately for left-side figures **(LEFT)** and right-side figures **(RIGHT)**. Error bars show standard deviation of different participants.

[27] A separate analysis of the side view (LS, RS) only reveals a significant effect of the factor VIEW with $F(1, 19) = 11.64$, $p < .01$, $\eta^2=.380$.

[28] This analysis was only conducted for the picture plane rotations (front, back, side views)

$$100/\left[(BA + \frac{FR - BA}{2}) * LS(or\ RS)\right] - 100$$

As shown in Figure 60, this leads to quite opposite effects for left-side compared to right-side figures. Again, this mirrored picture shows that obviously figures facing down (most prominent for LS225 and RS135) seem to come closer to the hypothetical midway position, while figures facing up (most prominent for LS135 and RS225) show that the time needed to get there on average exceeds the midway position by 28% (LS) to 40% (RS). Yet, it is visible that even though - when averaged - the 180° angle of rotation amounts to almost a perfect "halfway rotation" value, there is a large interindividual difference at this position.

Training effect

Participants showed an improved performance in the course of the experiment. This was obvious in significantly lower RT for the second two blocks compared to the first two blocks with $t(20) = 5.35$, $p < .001$. Error Rates at the same time did only marginally improve when comparing the first two blocks before the break with the following two blocks after the break ($p < .05$).

Another quite interesting training effect was that different angles were differently affected by improved performance (see Figure 61). The different improvement of performance for the different

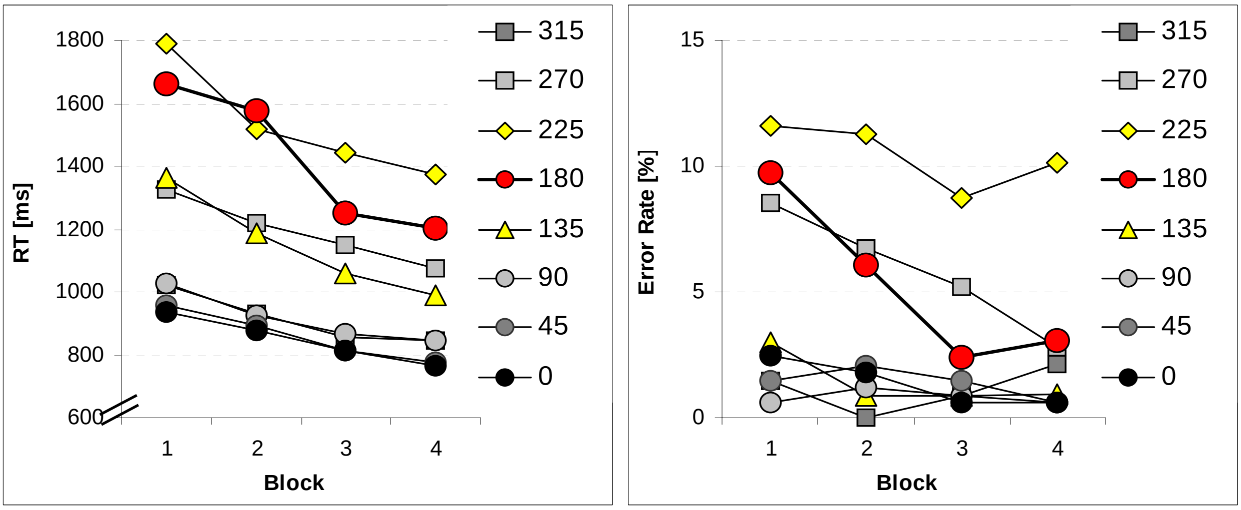

Figure 61 Improved performance (**LEFT**: lower RT and **RIGHT**: decrease of Error Rate) was different for the ANGLES of rotation (different symbols) tested.

angles speaks in favor of the view that some views are less well stored and trained than others; more cells are tuned to particular characteristic views such as the full face, profiles and back and more cells are tuned to the frontal views than to the back views (PERRETT ET AL., 1998).

Inspection of Figure 58 and Figure 59 reveal that even though figure rotations in the picture and depth plane were randomly presented within the same condition, the effects found in previous experiments are clearly comparable with the results gathered here. The nearly flat curve for small angles of rotation (0°, 45° and 90°) shows that people are able to judge and recognize figures at these orientations very fast. This improvement could also be considered as a change of strategy by changing from an analytical to a more holistic processing.

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7. General Discussion

General Effects Noticed in all of the Experiments: Post-Hoc Analyses

Effect of Practice

Response times in mental rotation tasks decrease substantially with training (e.g. BETHELL-FOX & SHEPARD, 1988). Also, not just the overall level of response time decreases, but also the slope of the response time function which relates processing time to the angular disparity – the mental rotation effect becomes smaller (see Figure 62). This suggests that the speed of mental rotation becomes faster. There are different views as to what exactly is improved by practice. BETHELL-FOX AND SHEPARD (1988) suggested that practice effects are due to the switch from element-wise transformation to Gestalt-transformation. This transition from an analytical strategy to a more holistic processing was also discussed by others (AMORIM ET AL,. 2006; WRAGA ET AL., 2003). In contrast, TARR AND PINKER (1989) assumed that practice merely leads to a memory storage causing decreased reaction times because there is no more need for computation (analogue to PERRETT ET AL., 1998).

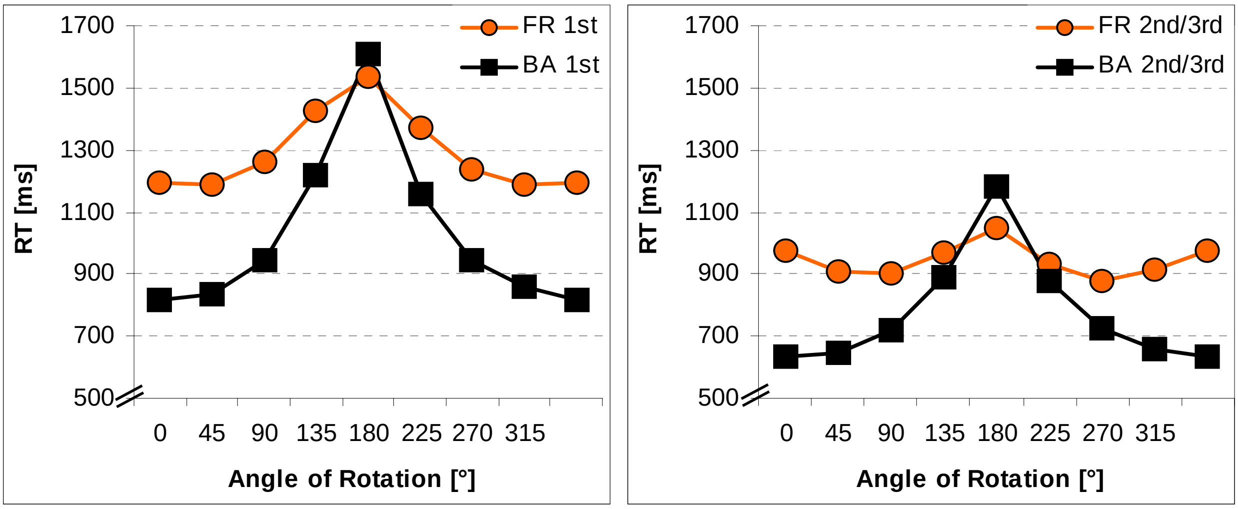

Figure 62 FRONT-BACK RT data of picture plane rotated figures gathered in EXP POS a/b, PLANE and OBJEGO as the 1st condition conducted (**LEFT**, N=15) and the same gathered for all the participants who conducted the picture plane rotation in upright position as their 2nd or 3rd condition (**RIGHT**, N=16)

The *process-based theories* (e.g. BETHELL-FOX & SHEPARD, 1988; WALLACE & HOFELICH, 1992) assume that redundant and inefficient processing steps are eliminated, that distinct subroutines are bound together to form larger units, and finally that distinct processes are utilized more efficiently (HEIL ET AL., 1998). These theories predict transfer of training independent of the particular type of perceptual input (STIGLER, NUSBAUM & CHALIP, 1988) and even unfamiliar situations will profit from training, as long as the same internal processes are evoked. *Instance-based theories* (e.g. TARR & PINKER, 1989) on the other hand assume that new and unfamiliar cognitive tasks are initially solved by using algorithms, i.e. by computing a solution, while after a while it will be solved by retrieving a previously stored solution. These solutions are traced in memory and practice strengthens the available memory trace. These theories predict little or no transfer; only conditions which are very similar to the training condition may cause transfer because only these will trigger the appropriate response associations in memory (HEIL ET AL., 1998). HEIL ET AL. (1998) tested these two theories with SHEPARD-METZLER objects and their data clearly favors the instance-based assumption by TARR AND PINKER (1989); obviously, the rotation process as such is not executed faster. They do not find that old stimuli presented from a new perspective are rotated at the same rate as the old stimuli from the known perspective. The authors however found minor transfer effects of trained nearby orientations (only for RT and not for ER) and suggest that a representation of a particular stimulus perspective is formed more easily (or earlier in practice) if the disparity is small, allowing for some generalization. Training effects therefore are quite specific and do not go beyond simple test-repetition effects. This suggests that the repetition of a mental rotation task leads to the formation of multiple representations of the various perspective views of an object. Representations become more and more established with training and can be accessed faster. This means that skilled subjects solve a mental rotation task more and more often by memory retrieval than by executing a genuine mental rotation (HEIL ET AL., 1998). This is in line with studies finding improved performance in mental rotation tasks with increased expertise; OZEL, LARUE AND DOSSEVILLE (2004) showed that athletes perform significantly faster than non-athletes in a mental imagery task. The overall decrease (independent form angular disparity) is allocated to increased speed of perceptual and motor processes not specific to mental rotation task. HEIL's theory does not deny the existence of the postulated mental operations; they most likely exist, and they have to be invoked by the unskilled to solve the task. However, with practice these resource-demanding operations become superfluous. Mental rotation can therefore be compared to other tasks such as learning mental calculation problems, learning the grammar of a foreign language or learning to drive. In any case, computation seems to be replaced by memory retrieval.

In the present data expertise did in fact lead to decreased reaction times, sometimes this was visible even within the same experimental condition as could be seen in EXP OBJEGO or improvement is visible between conditions (e.g. EXP POS-DEPTH). Furthermore different angles of rotation seemed to profit to a different degree from this training as could be seen in EXP 3D. However, figures presented at angles close to the upright started off at a very low level and improvement therefore was less likely than with poor performance for unfamiliar orientations (ceiling effect).

Are male participants better at mental rotation?

The effect of gender in mental rotation tasks has been discussed very controversially; the effects reported in literature indeed generally have been quite weak (e.g. KIMURA, 1996). MASTERS and SANDERS (1993) questioned gender differences found in various spatial tests and conducted a meta-analysis comparing effect size (d) of 14 studies which administered a Mental Rotation Test to adolescents and young adults. Males scored significantly higher than females in all the studies. Furthermore, the analyses of the d's computed for the studies revealed that the magnitude of the gender difference on the Mental Rotation Test has remained stable over time.

According to JORDAN ET AL. (2002), the strongest sex differences favoring men in any cognitive tasks, are found for tasks that require the mental rotation of three-dimensional objects. Yet, often the confounding factor is that the overall performance level is not matched between the sexes. The authors investigated functional brain activation patterns for males and females who did not differ in overall level of performance on three mental rotation tasks. They found common as well as distinct brain activations (e.g. men also showed an additional significant activation of the left motor cortex). JORDAN ET AL. (2002) conclude that there seem to be genuine between-sex differences in cerebral activation patterns during mental rotation even when performances are similar. Such differences suggest that men and woman use different strategies in mental rotation tasks.

A post-hoc analysis of all the data gathered focusing on gender differences was conducted for all of the 44 women and 57 men who took part in the mental rotation experiments. For this analysis – to get an overall view – the different angles of rotation, views and conditions were not separately considered and grouped together. This lead to the following results:

Men on average made faster mental rotation judgments in the experiments **POS-PICT (a)** (5%), **HANDSHAKE** (9%), **OBJEGO** (6%) and **3D** (10%) and showed higher reaction times than woman for the remaining experiments POS-PICT (b) (-6%), POS-DEPTH (-14%) and PLANE (16%)[29]. This result is quite striking, yet error rates also have to be considered:

The same analysis regarding error rates revealed that men in total made fewer mistakes in experiments **POS-PICT (a)** (12%), in **POS-PICT (b)** (30%), **PLANE** (26%), **HANDSHAKE** (21%) and in **3D** (42%). The remaining experiments showed a superior performance of women with men making more mistakes in the experiments POS-DEPTH (3%) and OBJEGO (6%).

The result of experiments POS-PICT (b) and PLANE fit well with an speed-accuracy tradeoff where men are slower but on average make less mistakes, the same holds true for the experiment OBJEGO where women are faster but show a higher error rate. The remaining experiments[30] POS-PICT (a), HANDSHAKE and 3D show superior performance of men regarding reaction times as well as error rates.

All in all, these data go well with many inconsistent reports on this matter and results seem to be quite strongly dependent on the sample tested and not a gender-dependent issue.

Effect of Laterality

Before participants started the experiments (HANDSHAKE, OBJEGO and 3D), they were asked to rotate spontaneously about their vertical axis and the direction they chose was noted. Also, eye dominance (acquired by asking them to look at me through a hole formed by their hands) and dexterity was noted for all of the participants in experiments HANDSHAKE, OBJEGO and 3D. Figure 63 shows the results of this explorative data. As has been argued in EXP 3D, reaction times for left-turn rotations seem to be favored over right-turn data. This was not in accordance with the participants "rotation preference" yet inspection of Figure 63 does indicate a trend in this direction where overall, more participants spontaneously did indeed rotate to the left.

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[29] These values were always considered relative to the women's performance, i.e. if women took 2000ms and men 1500 than this would lead to men being 33% faster or slower respectively.

[30] POS-PICT: 6 men and 7 women, EXP HANDSHAKE: 10 men and 6 woman

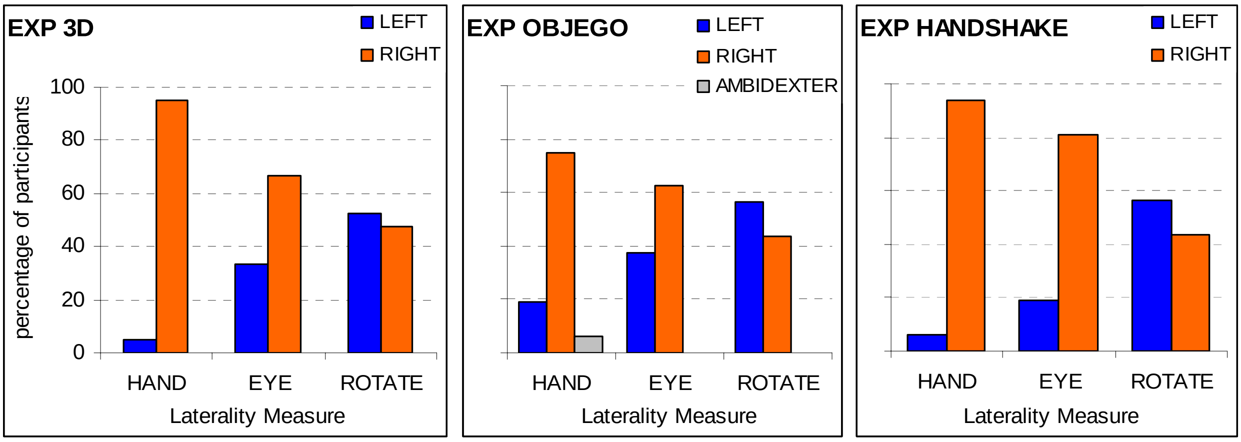

Figure 63 Laterality measures (handedness, HAND, eye dominance (EYE) and preferred rotation (ROTATE) shown for EXP 3D **(LEFT)**, OBJEGO **(MIDDLE)** and HANDSHAKE **(RIGHT)**.

"Cognitive Strategies"

Participants seem to accomplish mental rotation tasks with body figures in a rather holistic way (AMORIM ET AL., 2006). This concept however is not clear because mental rotation in general seems to be quite a flexible process that may involve analytical as well as holistic strategies (SMITH & DROR, 2001). A possible explanation to account for this ambiguous state could be that mental rotation stimuli, and even more so the human body figures applied in the present work, are increasingly processed in a holistic manner (subjective reports confirm this). According to the concept of shape matching, a spatial embodiment (bodily projection) should be able to assess the reference posture (top-bottom, feet-head, front-back, left-right). At the same time there is a motor embodiment where motor areas of the brain imitate the image-like posture of the stimulus' posture (AMORIM ET AL., 2006). AMORIM ET AL. (2006) postulate that the harder it is to imitate the posture (in accordance with the characteristics of the muscular-skeletal system) the more analytic the spatial transformation in a shape-matching process is. Participants in the present study report using "logical" inferences with image-specific cues of the applied body sketches (e.g. when the belly button was visible and the extended arm was to the right side of the screen then the correct answer is "left" or "if his arm is on the right and facing me, then the left button needs to be pressed" or "when the figure is facing me then it is the other arm than mine, when not, then it's the same arm"). In accordance with MICHELON AND ZACKS (2006) I predicted that such strategies would not be used because they require complicated verbal or mathematical computations; whereas the perspective transformation strategy allows one to read off the correct answer directly form a transformed spatial representation. By mixing different rotation planes in EXP 3D this assumption is confirmed and suggests that changes of strategies take time and seem to abolish incorporation of too complex cognitive strategies. The random presentation of figures in all different angles and in the front or back view is constantly demanding full concentration of the participant who have to be able to flexibly "apply" the requested and necessary transformation. People apply all possible spatial strategies as has been shown in selected experiments (EXP PLANE, EXP POS-PICT and EXP POS-DEPTH) however seem to differ in finding the most efficient ones; only some of the participants show a "flipping mechanism" as has been described by MURRAY (1997) where flipping of an inverted figure at 180° leads to decreased RT compared to the neighboring angles of rotation 135° and 225°. Furthermore, it seems as if more participants adopt this strategy when they are either placed in the prone or supine position or when the stimuli shown are restricted to rotations in the depth plane. Also, flipping is preferably applied for front view figures (which results in the "easy" back view figure at 0°) yet also shows selectively for back view figures.

The pronounced asymmetry effect found for figures rotated in the depth plane furthermore implies strong experience-dependence and body-related factors as discussed in EXP PLANE. An explanation for the altered processing for rotations in the depth plane could be found in the distinction of analogue transformation versus neural summation. PERRET ET AL. (1998) showed that viewpoints of familiar objects that are strongly represented reach threshold faster than less strongly represented viewpoints. Most obviously, data confirms that familiarity is important and the positions with most errors and highest reaction times are not perspectives that we encounter in daily life and therefore are not trained.

Effect of Stimuli

In the present experiments three different kinds of body figures were applied: sketches of bodies (EXP POS-PICT a & b), naturalistic looking body figures with their arm extended (EXP PLANE & OBJEGO) and naturalistic body figures extended their arm as if they were going to shake hands (EXP HANDSHAKE) (see Figure 64). We hypothesized that a more realistic figure would facilitate egocentric transformation. However, there does not seem to be a significant difference between mental rotation of sketches of bodies and more realistic looking pictures of bodies.

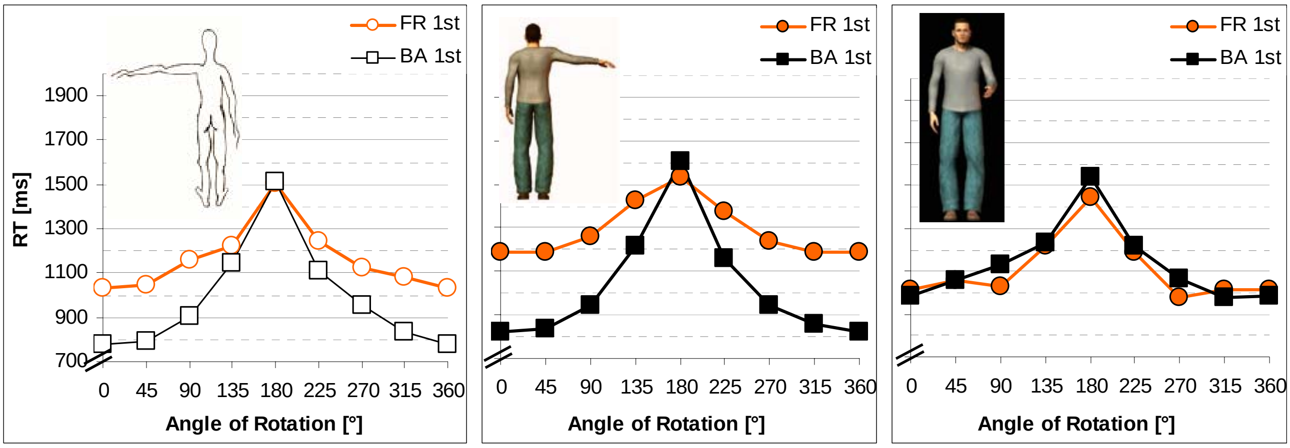

Figure 64 comparison of data with different stimuli used for the first condition only: **LEFT**: line drawings (N=10), **MIDDLE**: realistic body figures (POSER), N=15), **RIGHT**: realistic handshake body figures (N=7).

There is a slight trend of the realistic stimuli leading to higher reaction times; however this is most probably an effect of the sample (due to little number of participants). When only considering data of the first condition in EXP HANDSHAKE with the modified human figure, the reversed view-effect is quite diminished. However, comparison with "regular" body figures shows that front and back view figures show quite identical patterns and the level of reaction times ends up at just about midway between front and back view figures of the other experiments. We assumed that motor activation would be increased in the latter experiment. The increased motor activation provoked by the instruction and the more allocentric task seems to have "equalized" the view effect.

Effect of View

By analyzing back view and front view stimuli separately, different patterns of RT-increase could be revealed. The course for front view figures was nearly flat, however, in contrary to previous literature (JOLA & MAST, 2005; PARSONS, 1987; ZACKS ET AL., 1999) showed a significant effect of orientation (increase in response time with increasing angle). One possible explanation for this finding is that the body sketches as used by ZACKS ET AL. (2002) triggered other mechanisms than the figures applied here. His body sketches were a little bit more complex than the line drawings used in EXP POS-PICT and he investigated figures that also showed crossed arms. Back view stimuli in the experiments always lead to a clear orientation effect showing nearly linear relationship between RT and tilt. Back view figures require a mental alignment of one's body parallel to the picture plane without requiring an additional rotation in the picture plane.

Front view figures presented at 180° show shorter reaction times compared to the according back view figures (picture plane). This implies that strategies are applied flexibly (PARSONS, 1987A, Exp 3) finds a linear relationship for front view figures when these are situated in a constant, environment-specific context. Participants then seem unable to re-interpret the angle of rotation as if they were in a supine position (JOLA & MAST, 2005). EXP HANDSHAKE was indeed able to slightly reverse the advantage of back and front figure responses and the data shown for the four participants who participated in EXP HANDSHAKE as well as the according EXP PLANE suggest that if more participants are tested in both experiments the reversal might be more pronounced.

Most interestingly, the effect of orientation which is not reported consistently for front view figures is always present for human body figures in the experiment conducted here. Quite a striking result is that this effect unexpectedly disappears for the object-condition conducted with the camera (EXP OBJEGO) which was supposed to evoke object-centered transformations known to show strong effects of orientation.

Spatial compatibility

The factor VIEW is also significant in the depth condition. Here, congruency is always the same related to the factor view since the figures shown from the back always correspond to congruent responses, while front view figures always ask for incongruent answers.

When only considering congruency as the significant factor of the view effect ("Simon-Effect"; see EHRENSTEIN, 1994; SIMON & RUDELL, 1967) for picture plane rotations the following (very simplified) model can be considered (see Figure 65). Assuming that there is a linear increase of difficulty with increasing angle (weighting function beta) and at the same time congruent responses (left arm is in the left visual field combined with left button or right arm is on the right visual field combined with right button) are weighted with 1, neutral (no laterality in figure because arm is either showing vertically down or up as at 90° and 270°) case is weighted with 2, whereas incongruent answers are regarded as most difficult and are given the value 3 (left arm is presented in the right visual field, right arm in the left visual field). The calculated multiplicative model reveals a clear and strong orientation effect for back figures as noticed in all of the experiments but not for the front figures where there is a minor orientation effect. This picture does not show quite as clear in my data (see Figure 62), yet it comes intriguingly close to the data of ZACKS ET AL. (2002) in which he found a pronounced orientation effect for the same-different task for front view figures (allocentric matching?) and no significant orientation effect for the left-right decision task for front view figures only (egocentric matching?).The former (same-different task) relates more strongly to an allocentric matching process, while the latter (left-right) represents more of an egocentric matching task where participants are to judge the figure in relation to themselves. It is possible that back view figures can evoke egocentric matching very easily, however this advantage is decreased incrementally depending on angular disparity from our position relative to the figure. Front view figures on the other hand, in our view elicit a more allocentric processing leading to a generally higher level of RT reducing the orientation effect.

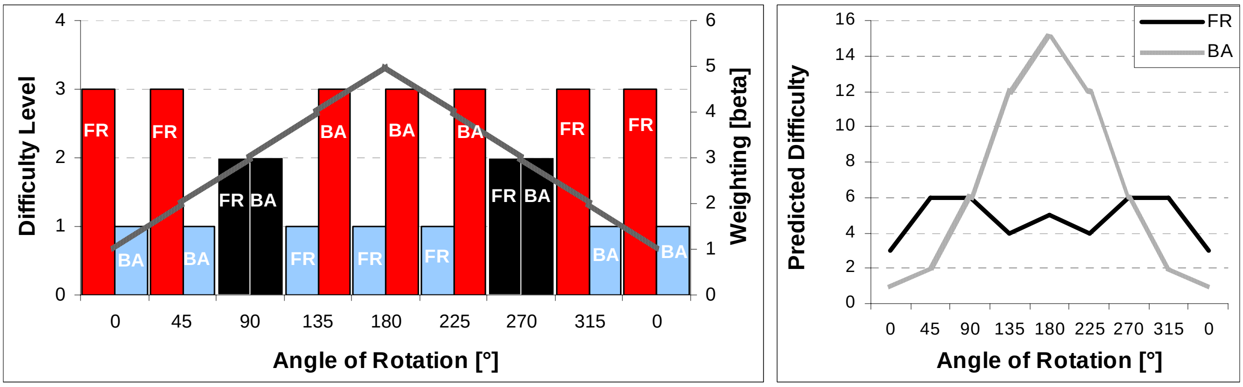

Figure 65 LEFT: suggested difficulty level for congruent (value 1), incongruent (value 3) and neutral (value 2) left-right decisions with a angular displacement specific (linear) weighting (beta; grey line). **RIGHT**: calculated model with predicted difficulty based on assumptions on the **LEFT**.

A post-hoc analysis of the front/back figures rotated in the picture plane for the upright position (EXP PICTDEPTH and OBJEGO) was conducted (see Figure 62) and lead to the following conclusions: Most obviously, congruency may add to the orientation effect but can not solely serve as an explanation. The additional rotation in the YAW-axis – the difference between the RT-curves at 0° (≈370ms for the first condition and 270ms for the second/third condition) – can be regarded as a further factor to be considered in the model.

Egocentric vs. Object-based Transformation

It seems plausible that participants search for the most efficient strategy to make their response no matter if they are to do an object-centered or an egocentric rotation. The assumption that both types of transformation base on different cognitive operations does not imply that there is no correlation between the performance in the two (HEGARTY & WALLER, 2004). PARSONS (1987A) considers a selection of spatial transformations, depending on the features of the stimulus and the angle of rotation. The selection of different strategies could possibly be influenced by the attributes of the experimental design and the instruction (PARSONS, 1987A). Mental change of perspective and mental rotation (egocentric vs. object-based transformation) rely on many common processes, such as the ability to code spatial images and to maintain these representations in memory (KOSSLYN, 1994). ZACKS AND TVERSKY (2005) suggest a multiple spatial transformation system that has developed to solve different spatial mental tasks. In everyday life we consider action plans that lead to egocentric, object-based transformations as well as a composition of the two.

The present data contribute to research on imagined transformations of the body. Information about possibly different spatial transformations and the accompanying internal representations can be useful in understanding some fundamental processes of spatial cognition (PARSONS, 1987A). The present work adds to the body of knowledge by expanding the tested range of angles of rotations with naturalistic body figures and shows that the transformation is strongly impaired when the figure is at "awkward" positions. The trend for reversal of the view-effect (found in all of the experiments including picture plane rotations), as shown for those four participants who took part in both EXP PLANE and EXP HANDSHAKE implies that the transformation applied is equally efficient for allocentric (rotation of the figure) and egocentric (taking over of the figure's perspective) transformations. In line with this, efficacy of object-centered transformation is strongly dependent on how strongly we associate manual actions with it. The more we are used to manipulate an object, the more strongly bodily restrictions are at play when we are to mentally rotate it.

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CLOSING WORDS

"All our theories are instrumental, are mental modes of adaptation to reality, rather than revelations or gnostic answers to some divinely instituted world-enigma."
W. JAMES (1907)

The questions posed at the beginning were what factors are involved when provided bottom-up information via the senses is consonant, dissonant or irrelevant to the task.

It seems that arousal and attention directed to irrelevant perceptual conditions are of major importance and affect cognitive processing accordingly by yielding a kind of dual-task situation. In EXP ACC-DEC it was impossible to ignore the vestibular stimulation, while results and subjective reports in EXP ROLL show that constant roll was easily shut out. When producing time intervals, a large variety of interval productions among the participants was found, however individual concepts of the required intervals remained stable across all of the experiments. The "extra" information of strong vestibular information lead to distinct changes of time productions in the course of time. It is difficult to make conclusive statements on how altered time productions were mediated. However, as could be seen in EXP ACC-DEC, the effect of slope for the 1s interval during deceleration and acceleration showed in opposite directions, suggesting that the effect was due to distinct inputs most probably mediated by vestibular signals. The effect found in EXP POS on the other hand suggests that other factors such as cognitive load, arousal and shared attention were of pivotal significance and lead to increased interval productions. The fact that only the 1s interval triggered reliable effects further suggests that the production of short intervals is more strongly affected by adding "noise" to the system. This "automatic" processing – reflecting the engagement of processes associated with the production of skilled movements – is more strongly biased than the more "cognitive" timing of longer intervals which depends on neural systems associated with attention and working memory (IVRY & SPENCER, 2004A). Longer intervals require more cognitive processes suggesting that focus is more strongly – if not entirely - set on the time production task.

The insights gathered in the mental rotation experiments show that - in selected cases – altered and more efficient mental rotation strategies can indeed be triggered if perceptual information is aligned with a human figure to be judged, yet this is not thoroughly the case with all of the participants and interindividual differences were clearly visible. This is in line with previous studies, suggesting that there are differences in the mental rotation skills and the according strategies; while some participants showed efficient strategies (flipping), others did not. However, all of the participants did show a strong decrease of reaction times in the course of time. Also, bottom-up perceptual information (body position) did not clearly trigger improved performance for distinct angles of rotation (probably due to the variety and randomization of angles) yet individual analysis points to altered strategies being more prominent when body position is aligned with the presented figures (especially for the inverted figure at 180°) suggesting the use of an egocentric (retinal) frame of reference. Furthermore, the distinction of egocentric and object-based transformations is called into question, suggesting that a clear difference needs to be made for objects related to the "graspability" and the possibility of embodiment and therefore yield very similar results found for mental rotation of body figures. Our position in space (or the interpretation thereof) seems to affect cognitive processes; the positions difficult to adapt in real life clearly cause more difficulty to respond to in the mental rotation tasks conducted. Not only seldom seen positions, but also positions implying a person "falling down" are affected and yield higher reaction times.

Can perception fool cognition? As mentioned in the introduction, cognition – the interpretation versus mere processing of a perceptual stimulus – is hard to shut out during "perceiving" and people are bound to analyze and consider any information present, even if this information is not directly relevant to the task. There however seems to be a weighting of information and when the sensory input does not reach a certain threshold, e.g. when it remains at a constant level it can be shut out more easily. The data obtained in the present work however suggests that the way we perceive and react to sensory input is always in the eye of the beholder.

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Last but not least I wish to thank all the participants for their patience and to some extent being willing to undergo considerable perceptual challenges.

CURRICULUM VITAE

PERSONAL DATA

Date of Birth: 14. September 1975

EDUCATION

03.05 – today	**Mediator SDM / Family Mediator SVM** Institut für systemische Entwicklung und Fortbildung (IEF), Zurich
09.03 – today	**PhD Student (50%)** Project leader of the research group "Multisensory Perception" General Psychology (Cognition), Institute of Psychology University of Zürich
10.96 – 12.03	**Master of Science** Major subject: General Psychology (Cognition) Minor subjects: Neurophysiology, Psychopathology of Children & Young Adults University of Zurich
10.95 – 09.96	**Beginning of studies** Major subject: Sociology University of Zürich
06.94 – 07.95	**1 year abroad: Summer School** Summer school course in Sociology Cuesta College, San Luis Obispo, USA
10.88 – 07.94	**Kantonsschule** Emphasis on modern languages Wetzikon

OCCUPATIONAL ACTIVITIES

03 – today	**Research Assistant** General Psychology (Cognition), Institute of Psychology, University of Zurich
00 – today	**Freelance work at external Department Evaluations** Departments evaluated included D-MATL, D-INFK, D-ERDW, D-BEPR, D-BAUG, D-PHYS, D-GESS and D-MAVT. ETH Zürich
01 – 02	**Course-related Internship in a psychological Counseling Practice (40%)** Dr. phil. R. Bühlmann, Zurich
00 – 03	**Various Term Assistances** Institute of Neuroinformatics (Prof. Dr. M-C. Hepp) and General Psychology (Prof. Dr. W. Marx) University of Zürich
00 – 01	**Scientific Assistant (50%)** Personal assistant to ongoing projects of Dr. T. Jarchow General Psychology (Cognition), Institute of Psychology, University of Zürich
99	**Translation work German-English (part-time)** Village Roadshow Company, Zurich
96 – 00	**Receptionist and Courier Service** BALTOS Service AG, Zurich
95 – 96	**Employee Information Service "111" (part-time)** Telecom, Winterthur
94 – 95	**Salesclerk** Gloria Jeans Café, Escondido, USA
	Factory Employee Ernie Ball, Guitar string company, San Luis Obispo, USA
90 – 03	**Private Lesson Teacher** of the subjects English, French, German, Mathematics and History Zurich and area

APPENDIX

Appendix 1: Instructions given in experiments

EXP ILLMOVE

„Stelle Dich so ein, dass du genau horizontal zum Boden (also so wie du im Bett liegen würdest) liegst. Mit dem Druckkästchen kannst du das Kippbrett bewegen und zwar kommen die Füsse höher zu liegen wenn Du den oberen Knopf betätigst und tiefer wenn Du den unteren Knopf drückst. Nach jeder Einstellung wird das Brett wieder weg von der zuletzt bestätigten Position fahren. Sobald der Motor wieder abstellt kannst Du die nächste Einstellung vornehmen."

Figure 66 Verbal instructions given in EXP ILLMOVE

Questions to ensure maintained illusory motion through constant eye movements were:

- How many dots do you see?
- How many complete circles can you see?
- How many incomplete circles can you see?
- How many rectangles can be made out of the black dots being in the corner?
- How many squares?
- How many triangles?
- How many equilateral triangles?
- How many different colors can you see?
- How many segments in a illusory circle?
- How often does blue appear in a circle segment?

Figure 67 Examples of eye-movement questions posed to during condition ILL to ensure constant perception of apparent motion

EXP ACC-DEC

Instruktionen Drehstuhlexperiment zur Zeitwahrnehmung (ACC)

Liebe Versuchsperson, wir möchten uns schon jetzt herzlich für Deine Teilnahme bedanken!

Zuerst müssen wir eine **Maske** anfertigen, um Deinen Kopf am Drehstuhl fixieren zu können. Nach der Fixierung beginnt das Experiment. Die Instruktionen stehen jeweils auf dem Bildschirm und werden gegebenenfalls auch von uns kommen.
Warte vor den einzelnen Trials jeweils auf unsere Instruktionen!

0. Baseline

Zuerst musst Du **OHNE ROTATION** verschiedene, gegebene Zeitintervalle abschätzen. Befolge dann die Instruktionen am Bildschirm.

☐ ☐ ☐ Drücke bei der **Zeitmessung** den **GELBEN KNOPF** um das Zeitintervall zu beginnen und drück jedesmal, wenn für Dich die gegebene Zeiteinheit vorbei ist wieder den GELBEN KNOPF. Wiederhol dies bis neue Instruktionen kommen.

1. Rotation

☐ ☐ ☐ Erst wenn wir das OK gegeben haben, kannst Du mit dem ROTEN KNOPF den Drehstuhl rotieren lassen. Befolge die Anweisungen auf dem Bildschirm.

☐ ☐ ☐ Zeitmessung = GELBER KNOPF wie bei der Baseline.

2. Imagery

Warte nun, bis Du gar kein Gefühl der Drehung mehr verspürst.
Versetz Dich während dieses Durchgang nochmals in die vorhergehende Rotation hinein und befolge die Anweisungen.

☐ ☐ ☐ Zeitmessung = GELBER KNOPF wie bei der Baseline.

3. Rotation

Danach kommt wieder die gleiche Bedingung/Rotation wie bei a.

Die Schritte 1-3 kommen, für jeweils verschiedene Zeitintervalle, 3 mal hinter einander.

Instruktionen Drehstuhlexperiment zur Zeitwahrnehmung (DEC)

Liebe Versuchsperson, wir möchten uns schon jetzt herzlich für Deine Teilnahme bedanken!

Zuerst müssen wir eine **Maske** anfertigen, um Deinen Kopf am Drehstuhl fixieren zu können. Nach der Fixierung beginnt das Experiment. Die Instruktionen stehen jeweils auf dem Bildschirm und werden gegebenenfalls auch von uns kommen.
Warte vor den einzelnen Trials jeweils auf unsere Instruktionen!

0. Baseline

Zuerst musst Du **OHNE ROTATION** verschiedene, gegebene Zeitintervalle abschätzen. Befolge dann die Instruktionen am Bildschirm.

☐ ☐ ☐ Drücke bei der **Zeitmessung** den **GELBEN KNOPF** um das Zeitintervall zu beginnen und drück jedesmal, wenn für Dich die gegebene Zeiteinheit vorbei is wieder den GELBEN KNOPF. Wiederhol dies bis neue Instruktionen kommen.

1. Rotation

☐ ☐ ☐ Erst wenn wir das OK gegeben haben, kannst Du mit dem ROTEN KNOPF den Drehstuhl rotieren lassen. Befolge die Anweisungen auf dem Bildschirm.

☐ ☐ ☐ Zeitmessung = GELBER KNOPF wie bei der Baseline.

2. Imagery

Warte nun, bis Du gar kein Gefühl der Drehung mehr verspürst.
Versetz Dich während dieses Durchgang nochmals in die vorhergehende Rotation hinein und befolge die Anweisungen.

☐ ☐ ☐ Zeitmessung = GELBER KNOPF wie bei der Baseline.

3. Rotation

Danach kommt wieder die gleiche Bedingung/Rotation wie bei a.

Die Schritte 1-3 kommen, für jeweils verschiedene Zeitintervalle, 3 mal hinter einander.

Figure 68: Written instructions given in the two sessions in EXP ACC/DEC

EXP POS/ROLL

Liebe Versuchsperson

Zuerst einmal vielen Dank für Deine Bereitschaft bei diesem Versuch mitzumachen!

Das Experiment befasst sich mit der Zeitwahrnehmung.

Erst wirst Du in der Humanzentrifuge gut eingepackt. Im Experiment wirst du langsam und kontinuierlich seitwärts gedreht, dabei musst Du durch Drücken des Knopfes an Deinem Helm verschiedene Zeitintervalle produzieren (1s, 3s, 8s). Der Versuchsleiter wird Dir stets die genauen Anweisungen geben.

Der START erfolgt mit dem ersten Drücken des Knopfes, damit wird die Maschine in Bewegung gesetzt. Dieser Klick gilt gleichzeitig als Beginn der ersten Intervall-Produktion und ab dann drücke den Knopf im Abstand des verlangten Intervalls.

Gebe solange Intervalle ab bis die Maschine wieder zu einem Stillstand kommt. Du wirst stets in dieselbe seitliche Richtung gefahren und dabei etwas mehr als 360° gedreht.

Der Versuchsleiter steht jederzeit mit Dir in Verbindung und hört Dich. Du kannst den Versuch jederzeit abbrechen oder mitteilen wenn Du eine Pause machen möchtest.

Der erste Versuchsdurchgang erfolgt ohne Drehung, hier kannst Du auch genau wie oben – nach dem Startsignal durch den Versuchsleiter – die Intervalle produzieren.

Wende Dich jetzt bitte an den Versuchsleiter.

Figure 69 Written instructions given in EXP ROLL

EXP PLANE

Liebe Versuchsperson

In diesem Experiment erscheinen Figuren am Bildschirm, die jeweils den linken oder rechten Arm ausgestreckt halten. Die Stimuli werden in verschiedenen Rotationswinkel und in zwei Ansichten (vorne / hinten) präsentiert.

Deine Aufgabe besteht darin, so schnell und so richtig wie möglich die entsprechende Maustaste zu klicken: Linker Arm → Linke Maustaste / Rechter Arm → Rechte Maustaste). Versuche dabei, möglichst wenig Fehler zu machen.

Das Experiment besteht aus zwei Teilen: In einem Teil rotieren die Stimuli in der Bildebene, im anderen Teil in der Tiefenebene.

Rotation in der Bildebene

Rotation in der Tiefenebene

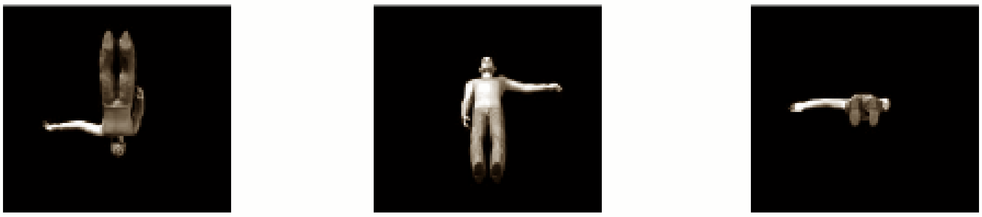


Figure 71 Written instructions given in EXP PLANE

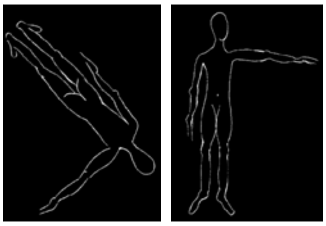
EXP POS-PICT/DEPTH

Instruktion Exp Body Image

Liebe Versuchsperson,

Im folgenden Experiment gilt es zu beurteilen, ob die präsentierten Figuren jeweils ihren linken oder rechten Arm ausgestreckt halten. Die Stimuli werden in verschiedenen Rotationswinkel präsentiert und Du wirst die Aufgabe in drei verschiedenen Körperpositionen ausführen.

Die Stimuli sehen bspw. so aus:



Klicke so schnell wie möglich auf die entsprechende Maustaste (links für linker Arm und rechts für rechten Arm), versuche aber auch möglichst wenig Fehler zu machen.

Herzlichen Dank für Deine Teilnahme

Figure 72 Written instructions given in EXP POS-PICT

Liebe Versuchsperson

In diesem Experiment erscheinen Figuren am Bildschirm, die jeweils den linken oder rechten Arm ausgestreckt halten. Diese Figuren werden in verschiedenen Rotationswinkel in der Tiefenebene und in zwei Ansichten (vorne / hinten) präsentiert. Sie sehen z.B. so aus:

Rotation in der Tiefenebene

Deine Aufgabe besteht darin, **so schnell und so richtig wie möglich** die entsprechende Maustaste zu klicken:

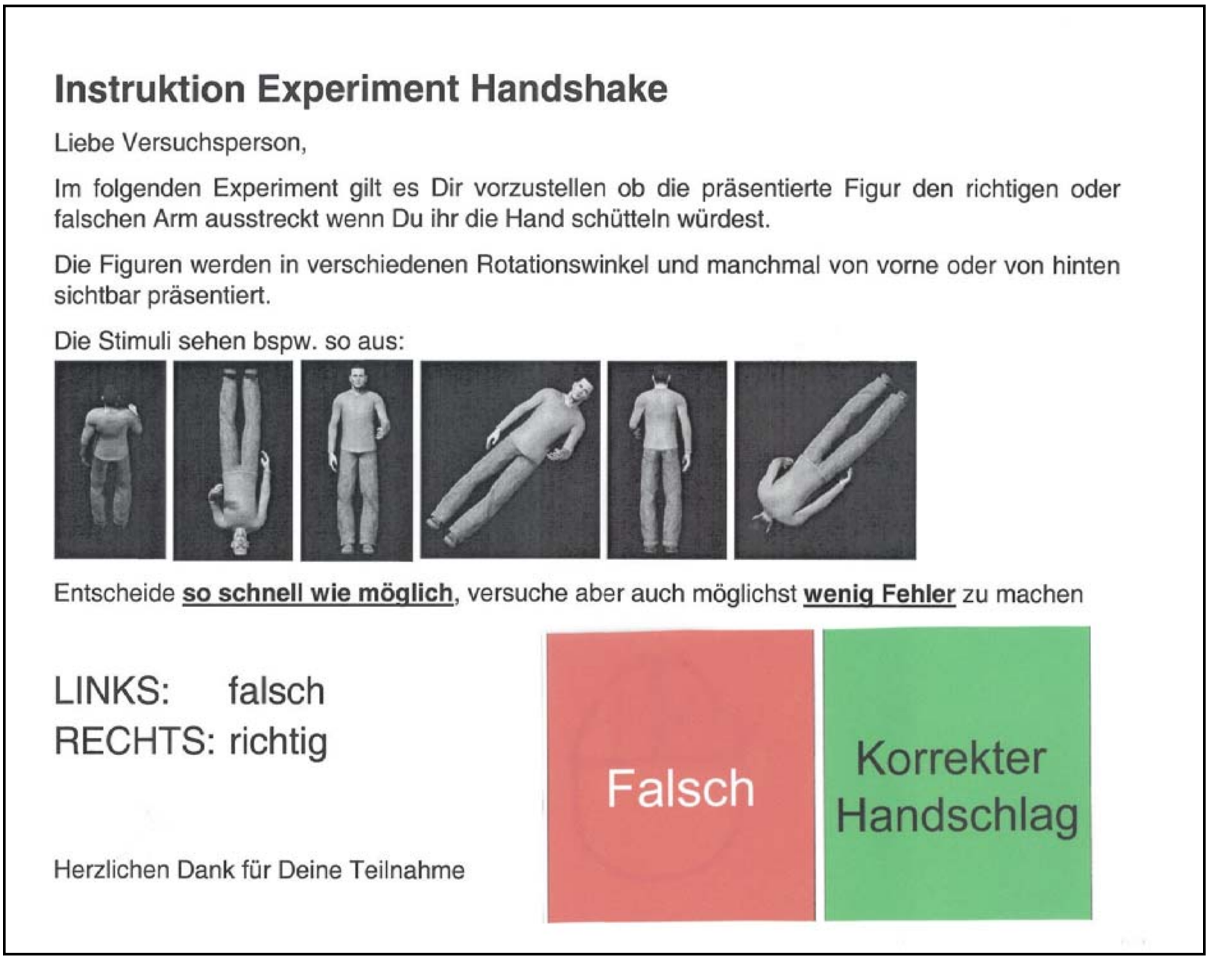
Linker Arm → Linke Maustaste
Rechter Arm → Rechte Maustaste

Versuche dabei, möglichst wenig Fehler zu machen.

Du wirst das Experiment in 3 verschiedenen Körperpositionen durchführen: aufrecht sitzend, auf dem Rücken und auf dem Bauch liegend.

Figure 73 Written instructions given in EXP POS DEPTH

EXP HANDSHAKE



Instruktion Experiment Handshake

Liebe Versuchsperson,

Im folgenden Experiment gilt es Dir vorzustellen ob die präsentierte Figur den richtigen oder falschen Arm ausstreckt wenn Du ihr die Hand schütteln würdest.

Die Figuren werden in verschiedenen Rotationswinkel und manchmal von vorne oder von hinten sichtbar präsentiert.

Die Stimuli sehen bspw. so aus:

Entscheide **so schnell wie möglich**, versuche aber auch möglichst **wenig Fehler** zu machen

LINKS: falsch
RECHTS: richtig

Falsch

Korrekter Handschlag

Herzlichen Dank für Deine Teilnahme

Figure 74 Written instructions given in Experiment HANDSHAKE; the colored piece of paper was placed under the serial mouse to ensure correct responses (half of the participant received instructions with the opposite task: for correct handshake press left, for incorrect press right.

EXP OBJEGO

Liebe Versuchsperson

In diesem Experiment erscheinen Kameras am Bildschirm, die den Auslöserknopf jeweils rechts oder links haben. Diese Kameras werden in verschiedenen Rotationswinkeln in der Frontalebene und in zwei Ansichten (von vorne / hinten) präsentiert. Sie sehen z.B. so aus:

Deine Aufgabe besteht darin **so schnell und so fehlerfrei wie möglich** zu entscheiden ob der Auslöserknopf links oder rechts ist und die entsprechende Maustaste zu klicken:

Auslöser links → Linke Maustaste
Auslöser rechts → Rechte Maustaste

Drehe dazu stets die **Kamera zu Dir hin,** so wie wenn Du ein Foto machen würdest.

Liebe Versuchsperson

In diesem Experiment erscheinen Figuren am Bildschirm, die jeweils den linken oder rechten Arm ausgestreckt halten. Diese Figuren werden in verschiedenen Rotationswinkel in der Frontalebene und in zwei Ansichten (vorne / hinten) präsentiert. Sie sehen z.B. so aus:

Deine Aufgabe besteht darin **so schnell und so fehlerfrei wie möglich** zu entscheiden ob der linke oder rechte Arm ausgestreckt ist und die entsprechende Maustaste zu klicken:

Linker Arm → Linke Maustaste
Rechter Arm → Rechte Maustaste

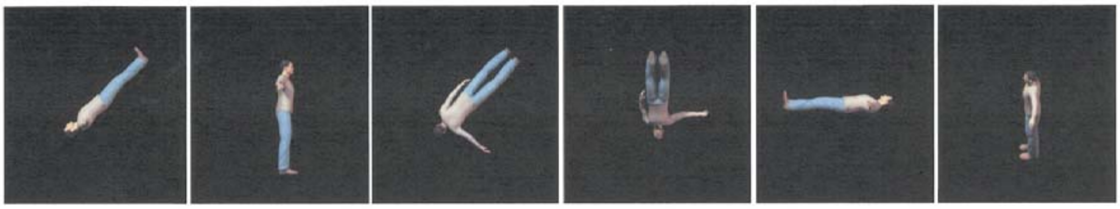
Drehe Dich dazu **in die Figur rein** und übernehme deren Perspektive, um Dein Urteil zu fällen.

Figure 75 Written instructions given in EXP OBJEGO; **TOP:** condition OBJ and **BOTTOM:** condition EGO

EXP 3D

Liebe Versuchsperson

In diesem Experiment erscheinen Figuren am Bildschirm, die jeweils den linken oder rechten Arm ausgestreckt halten. Diese Figuren werden in verschiedenen Rotationswinkeln und in zwei Ansichten (vorne / hinten) präsentiert. Sie sehen z.B. so aus:



Deine Aufgabe besteht darin **so schnell und so fehlerfrei wie möglich** zu entscheiden ob der linke oder rechte Arm ausgestreckt ist und die entsprechende Maustaste zu klicken:

Linker Arm → Linke Maustaste
Rechter Arm → Rechte Maustaste

Figure 76 Written instructions given in EXP 3D; the participants were also explicitly urged to “take over the perspective of the figure”.

Appendix 2: DEPTH PLANE Questionnaire

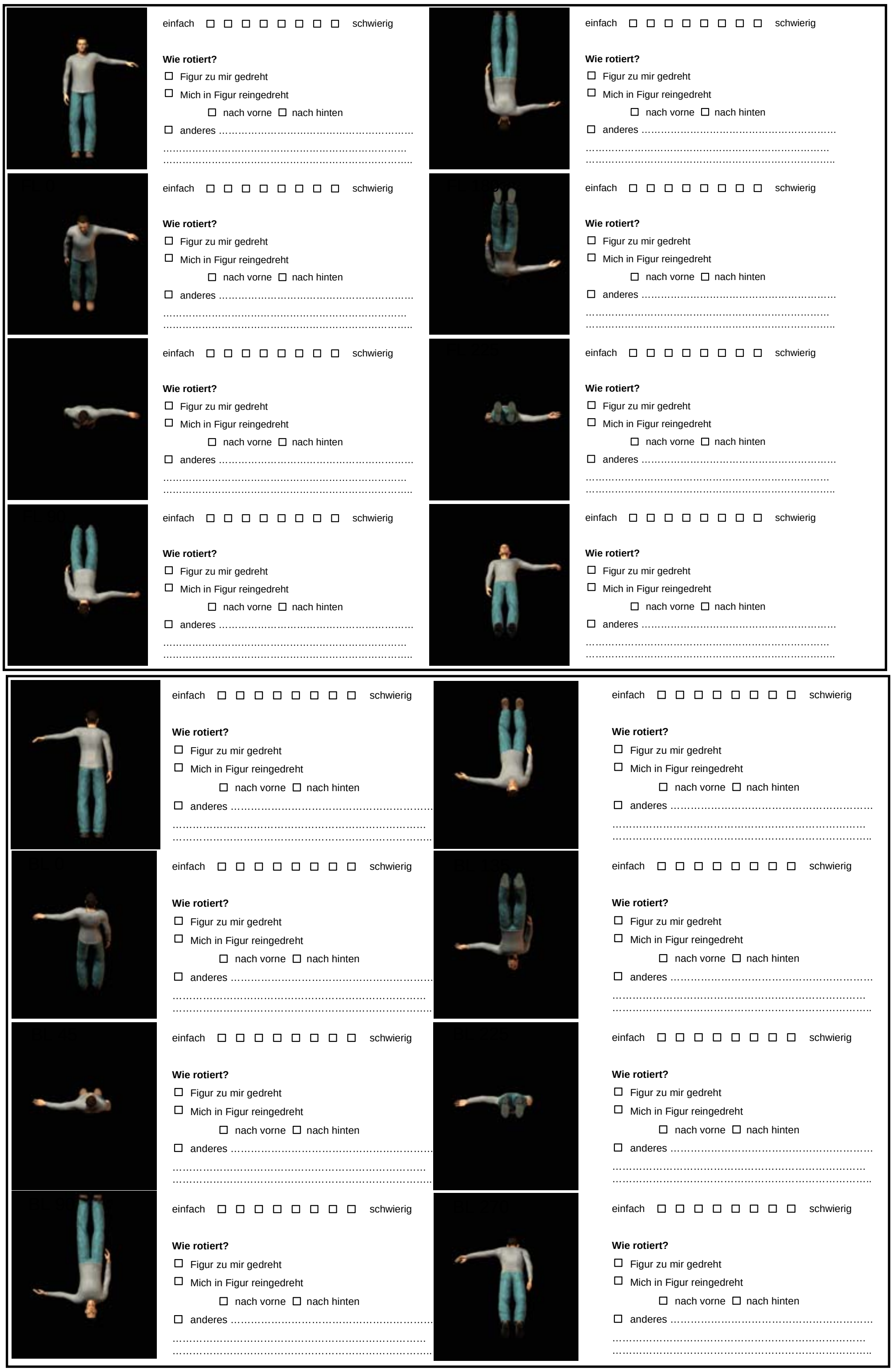


Figure 77 Questionnaire; only data of difficulty rating was analysed, the other questions turned out to be confusing and were often misunderstood.

Appendix 3: Overview of Participants

EXPERIMENT	VP#	SEX	AGE	HAND	EYE	ROTATION	ORDER
EXP NOILL	1	m	29	RE	RIGHT	LEFT	NO-ILL
	2	w	23	RE	RIGHT	RIGHT	NO-ILL
	3	m	25	RE	RIGHT		NO-ILL
	4	m	25				ILL-NO
	5	m	35	RE	RIGHT	RIGHT	ILL-NO
	6	m	23				ILL-NO
	7	m	29	RE	LEFT	LEFT	ILL-NO
	8	m	26	RE	RIGHT		ILL-NO
	9	m	27				NO-ILL
	10	m	31	RE	RIGHT	RIGHT	ILL-NO
	11	m	35	RE	RIGHT	RIGHT	NO-ILL
	12	w	25				NO-ILL
EXP ACCDEC	13	w	39				ACC-DEC
	14	w	30	RE	LEFT	LEFT	ACC-DEC
	15	m	31				DEC-ACC
	16	m	32	RE	LEFT	RIGHT	DEC-ACC
	3	m	27	RE	RIGHT		ACC-DEC
	17	m	28				DEC-ACC
	18	m	25				ACC-DEC
	19	w	27				DEC-ACC
	20	w	24	RE	RIGHT	LEFT	ACC-DEC
	21	m	26	RE	both	LEFT	DEC-ACC
	22	m	26				DEC-ACC
	23	m	32	NOT COMPLETED			
	24	m	34				ACC-DEC
EXP ROLL-POS	25	m	26	RE	RIGHT	RIGHT	ROLL-STATIC
	26	m	22	RE	LEFT	LEFT	ROLL-STATIC
	2	w	25	RE	RIGHT	RIGHT	ROLL-STATIC
	27	m	29	RE			ROLL-STATIC
	1	m	31	RE	RIGHT	LEFT	ROLL-STATIC
	20	w	25	RE	RIGHT	LEFT	ROLL-STATIC
	11	m	36	RE	RIGHT	RIGHT	ROLL-STATIC
	14	w	30	RE	LEFT	LEFT	ROLL-STATIC
	28	m	22				ROLL-STATIC
	29	w	25				ROLL-STATIC
	30	w	19	NOT COMPLETED			ROLL-STATIC
	31	w	20				ROLL-STATIC
	32	m	22				ROLL-STATIC
	33	w	26				ROLL-STATIC
	34	w	23				ROLL-STATIC

EXP POS-PICT (a)	14	w	29	RE	LEFT	LEFT	SUP-SIDE-UP
	19	w	27	RE			UP-SUP-SIDE
	20	w	24	RE			SIDE-SUP-UP
	35	w	28	RE	RIGHT	RIGHT	UP-SIDE-SUP
	2	w	24	RE	RIGHT	RIGHT	SUP-UP-SIDE
	36	w	28	RE	RIGHT	RIGHT	SIDE-UP-SUP
	11	m	35	RE	RIGHT	RIGHT	UP-SIDE-SUP
	1	m	30	RE	RIGHT	LEFT	SUP-UP-SIDE
	37	m	34	RE			SIDE-SUP-UP
	10	m	32	RE	RIGHT	RIGHT	UP-SUP-SIDE
	3	m	26	RE	RIGHT		SIDE-UP-SUP
	38	m	29	RE			SUP-SIDE-UP
	39	w	29	LI	RIGHT		SUP-SIDE-UP
EXP POS-PICT(b)	40	w	34	LI	LEFT	LEFT	UP-SUP
	41	m	35	RE			SUP-UP
	42	m	22	RE			UP-SUP
	43	m	34	RE			SUP-UP
	44	m	35	RE			UP-SUP
	45	m	33	RE			SUP-UP
	46	w	32	RE			SUP-UP
	47	m	37	RE			UP-SUP
	48	w	36	RE			SUP-UP
	49	w	19	RE			UP-SUP
	50	m	34	RE			SUP-UP
	51	m	40	RE			UP-SUP
	52	w	34	RE			SUP-UP
EXP PLANE	25	m	26	RE	RIGHT	RIGHT	DEPTH-PICT
	53	m	27	RE	RIGHT		PICT-DEPTH
	54	m	29	RE	RIGHT		DEPTH-PICT
	26	m	22	RE	LEFT	LEFT	PICT-DEPTH
	55	m	22	RE	LEFT		PICT-DEPTH
	56	w	34	RE			PICT-DEPTH
	57	w	33	RE			PICT-DEPTH
	58	m	32	RE			DEPTH-PICT
	59	w	32	RE			PICT-DEPTH
	60	m	36	RE			DEPTH-PICT
	61	m	34	RE			PICT-DEPTH
	62	w	34	RE			PICT-DEPTH
	63	w	27	RE			DEPTH-PICT
	64	w	32	RE			DEPTH-PICT
	65	w	35	RE			DEPTH-PICT
	66	w	37	RE			DEPTH-PICT
EXP POS-DEPTH	10	m	33	RE	RIGHT	RIGHT	PRONE-UP-SUP
	14	w	30	RE	LEFT	LEFT	SUP-PRONE-UP
	26	m	22	RE	LEFT	LEFT	UP-SUP-PRONE
	67	w	24	LI	RIGHT	LEFT	PRONE-SUP-UP
	68	m	27	RE	RIGHT	LEFT	UP-PRONE-SUP
	69	w	22	RE	LEFT	LEFT	PRONE-SUP-UP
	70	m	25	LI	LEFT	LEFT	UP-PRONE-SUP
	71	m	29	RE	RIGHT	LEFT	SUP-PRONE-UP
	72	m	24	RE	RIGHT	RIGHT	PRONE-SUP-UP
	73	m	31	RE	LEFT	RIGHT	UP-SUP-PRONE
	74	m	22	RE	RIGHT	LEFT	SUP-UP-PRONE
	75	w	25	RE	LEFT	LEFT	PRONE-UP-SUP
	76	m	24	RE	RIGHT	LEFT	SUP-PRONE-UP
	77	w	32	RE	RIGHT	RIGHT	SUP-UP-PRONE
	78	m	26	RE	LEFT	LEFT	PRONE-SUP-UP
	79	w	23	RE	LEFT	RIGHT	SUP-PRONE-UP
	80	w	27	RE	RIGHT	RIGHT	UP-PRONE-SUP
	11	m	37	RE	RIGHT	RIGHT	PRONE-UP-SUP
	81	m	37	RE		LEFT	SUP-UP-PRONE
	82	w	16	RE		LEFT	PRONE-UP-SUP
	83	w	20	RE		LEFT	SUP-UP-PRONE
	40	w	35	LI	LEFT	LEFT	UP-SUP-PRONE
	57	w	34	RE			UP-SUP-PRONE
	48	w	38	RE		LEFT	UP-PRONE-SUP

EXP HANDSHAKE	25	m	26	RE	RIGHT	RIGHT	DEPTH-PICT
	84	w	22	RE	LEFT	RIGHT	PICT-DEPTH
	55	m	22	RE	RIGHT	LEFT	DEPTH-PICT
	85	m	25	RE	RIGHT	LEFT	DEPTH-PICT
	86	w	30	RE	RIGHT	LEFT	DEPTH-PICT
	20	w	22	RE	RIGHT	LEFT	DEPTH-PICT
	2	w	25	RE	RIGHT	RIGHT	PICT-DEPTH
	5	m	38	RE	RIGHT	RIGHT	DEPTH-PICT
	87	m	29	RE	RIGHT	LEFT	PICT-DEPTH
	89	m	24	RE	RIGHT	LEFT	PICT-DEPTH
	90	w	23	RE	LEFT	LEFT	DEPTH-PICT
	53	m	28	RE	RIGHT	RIGHT	DEPTH-PICT
	38	m	30	RE	RIGHT	LEFT	PICT-DEPTH
	40	w	35	LI	LEFT	LEFT	PICT-DEPTH
	11	m	37	RE	RIGHT	RIGHT	PICT-DEPTH
	88	m	38	RE	RIGHT	RIGHT	PICT-DEPTH
EXP OBJEGO	16	m	33	RE	LEFT	RIGHT	EGO-OBJ
	91	m	33	RE	LEFT	LEFT	OBJ-EGO
	92	m	36	RE	RIGHT	RIGHT	OBJ-EGO
	93	w	34	AMBIDEXTER	RIGHT	RIGHT	EGO-OBJ
	94	m	33	RE	LEFT	LEFT	EGO-OBJ
	21	m	28	RE	RIGHT	LEFT	OBJ-EGO
	95	w	27	LI	RIGHT	LEFT	EGO-OBJ
	96	w	31	RE	RIGHT	LEFT	OBJ-EGO
	97	m	28	RE	RIGHT	RIGHT	EGO-OBJ
	98	w	30	RE	RIGHT	RIGHT	OBJ-EGO
	99	w	38	LI	RIGHT	RIGHT	OBJ-EGO
	100	w	32	RE	LEFT	LEFT	EGO-OBJ
	20	w	23	RE	RIGHT	LEFT	EGO-OBJ
	101	m	27	LI	LEFT	LEFT	EGO-OBJ
	102	m	30	RE	LEFT	LEFT	OBJ-EGO
	103	w	29	RE	RIGHT	RIGHT	OBJ-EGO
EXP 3D	104	m	30	RE	LEFT	LEFT	
	105	m	34	RE	RIGHT	LEFT	
	106	m	29	RE	LEFT	LEFT	
	26	m	23	RE	LEFT	RIGHT	
	1	m	31	RE	RIGHT	LEFT	
	86	w	31	RE	RIGHT	RIGHT	
	42	m	24	RE	RIGHT	LEFT	
	107	w	23	LI	RIGHT	RIGHT	
	108	w	23	RE	RIGHT	LEFT	
	109	w	26	RE	RIGHT	RIGHT	
	11	m	37	RE	RIGHT	RIGHT	
	20	w	23	RE	RIGHT	LEFT	
	110	w	24	RE	RIGHT	RIGHT	
	111	m	30	RE	RIGHT	RIGHT	
	112	m	31	RE	LEFT	LEFT	
	7	m	31	RE	LEFT	LEFT	
	113	w	23	RE	RIGHT	RIGHT	
	10	m	34	RE	RIGHT	RIGHT	
	14	w	31	RE	LEFT	LEFT	
	114	m	32	RE	RIGHT	RIGHT	
	55	m	23	RE	LEFT	LEFT	